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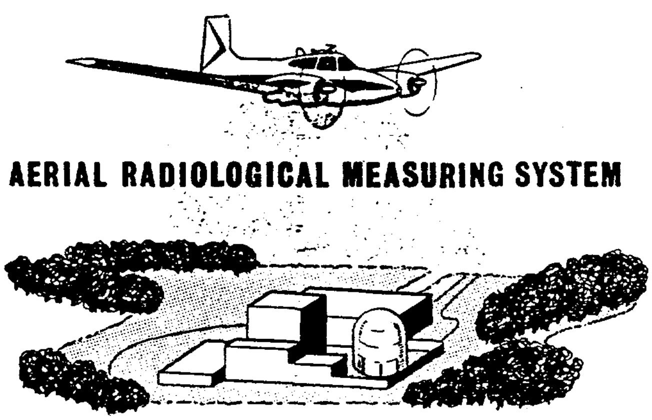

AERIAL RADIOLOGICAL SURVEYS OF ERDA'S OAK RIDGE FACILITIES AND VICINITY (SURVEY PERIOD: 1973-1974)

15 FEBRUARY 1976

LAS VEGAS AREA OPERATIONS
EG&G, INC., 680 E. SUNSET RD.,
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AERIAL RADIOLOGICAL SURVEYS OF ERDA'S OAK RIDGE FACILITIES AND VICINITY

(SURVEY PERIOD: 1973-1974)

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REVISION NOTICE PAGE

The following pages of "Aerial Radiological Surveys of ERDA's Oak Ridge Facilities and Vicinity (Survey Period: 1973-1974)," EGG-1183-1682 dated 15 February 1976 have been revised.

Page 38	First paragraph, ninth line – change 'equatic' to "aquatic'
Pages 60 and 61	Please replace Table C1 with the attached corrected table.
Page 103	Figure F-1 caption – second line – change from 'at 75m altitude,' to 'at 45m altitude,'

Table C-1. Spectral Data

Spectrum No.	Reference Figure No.	Area	Line No.	S. C.	Records	Live Time (sec)	Date	Inferred Isotopes
I		Background	81	407	1-30	84.1	11/13/74	Natural
II		Ecology area	64	462	8-12	14.2	11/13/74	^{60}Co & ^{137}Cs
III		Net over ecology area	64	462	8-12	14.2	11/13/74	^{60}Co & ^{137}Cs
I-V		Background	52A	756	36-39	10.3	11/20/74	Natural
V		Fuel fab. plant	52A	756	52-55	10.0	11/20/74	^{235}U
V-I		Net over fuel fab. plant	52A	756	52-55	10.0	11/20/74	^{235}U
1	11	Island	A-37	162	4-5	5.3	11/8/74	^{137}Cs & ^{60}Co
2	12	Bank west of K-25	26	137	14-18	14.0	11/8/74	^{137}Cs & ^{60}Co
3	12	Water treatment plant	51	262	51-65	41.6	11/9/74	^{137}Cs & ^{60}Co
4	14	K-25	28	141	28-39	28.1	11/8/74	^{234m}Pa
5	14	K-25	16	108	38-45	18.5	11/8/74	^{234m}Pa
6	14	K-25	23	129	17-19	7.7	11/8/74	^{137}Cs
7	15	White wing scrap yard	121-123	559-567	-	49.6	11/15/74	^{137}Cs & ^{234m}Pa
8	15	White wing scrap yard	120-123B	728-731	-	50.0	11/20/74	^{234}Th & ^{235}U
9	17	Ecology study area	64	462	8-12	14.2	11/13/74	^{60}Co & ^{137}Cs
10	18	X-10, burial ground #3	83B	622	2-7	17.7	11/16/74	^{60}Co & ^{137}Cs
11	18	X-10	79	411	72-73	5.6	11/13/74	^{137}Cs
12	18	X-10, laboratory	79	411	76-81	15.8	11/13/74	^{60}Co & ^{137}Cs
13	18	X-10, laboratory	83B	622	17-20	10.0	11/16/74	^{137}Cs
14	18	X-10	91	367	34-35	5.1	11/12/74	^{137}Cs
15	18	X-10, former ILW trench	93B	612	15-17	8.8	11/16/74	^{137}Cs
16	18	X-10, burial ground #4	93B	612	22-25	9.4	11/16/74	^{60}Co & ^{137}Cs
17	18	X-10, pilot plant	96	346	18-21	9.2	11/12/74	^{137}Cs
18	18	X-10, ILW pumping station	96	346	15-17	8.1	11/12/74	^{137}Cs
19	18	X-10, HFIR	101	334	16-19	10.3	11/12/74	^{60}Co
20	18	X-10, burial ground #5	101	334	23-26	9.7	11/12/74	^{60}Co & ^{137}Cs
21	18	X-10, White Oak Lake	99B	604	20-22	7.0	11/16/74	^{60}Co & ^{137}Cs
22	18	X-10, White Oak Lake	99B	604	14-17	8.9	11/16/74	^{60}Co & ^{137}Cs
23	18	X-10, White Oak Lake	101	334	43-45	7.3	11/12/74	^{60}Co & ^{137}Cs
24	18	Ecology study plots	91	367	49-51	7.9	11/12/74	^{137}Cs
25	19	X-10, 7000 area	89A	377	10-12	6.5	11/12/74	^{137}Cs

Table C-1. Spectral Data (Continued)

Spectrum No.	Reference Figure No.	Area	Line No.	S. C.	Records	Live Time (sec)	Date	Inferred Isotopes
26	19	Ecology study area	81	407	103-106	11.2	11/13/74	^{60}Co & ^{137}Cs
27	19	X-10 (church & cometary)	83 & 84	387, 389	-	5.6	11/12/74	-
28	20	Ecology area near HPRR	116	672	-	13.3	11/16/74	^{137}Cs
29		East Fork Popular Creek - Y-12	-	030	19-28	27.4	11/7/74	-
30	21	East Fork Popular Creek	-	036	50-63	37.4	11/7/74	^{137}Cs
31	22	Y-12 Burial ground	153	547	79-84	14.9	11/15/74	^{234m}Pa
32	23	Y-12	151	543	31-34	9.5	11/15/74	^{208}Tℓ
33	24	Y-12	153	547	14-22	23.7	11/15/74	^{137}Cs
34	24	Y-12	150	536	63-68	16.4	11/15/74	^{137}Cs
35	24	Y-12	156	553	51-54	10.7	11/15/74	X-rays
36	24	Y-12	153	547	31-37	17.2	11/15/74	^{234m}Pa & ^{137}Cs
37	24	Y-12	150	536	53-59	10.6	11/15/74	^{234m}Pa
38	24	Y-12	148	532	53-54	4.3	11/15/74	^{234m}Pa & ^{208}Tℓ
39	24	Y-12	150	536	43-48	13.4	11/15/74	^{234m}Pa
40	24	Y-12	150	536	28-32	13.6	11/15/74	^{234m}Pa
41	F1	U. S. Nuclear plant	52A	756	52-55	10.0	11/20/74	^{235}U
42	F2	American Nuclear site	168	836	10-18	20.0	11/21/74	^{60}Co

ABSTRACT

Airborne radiological surveys of the area surrounding ERDA's Oak Ridge facilities were made in September 1973 and again in November 1974 by EG&G, Inc. for the United States Energy Research and Development Administration, Division of Operational Safety. The surveys consisted of airborne measurements of gamma radiation from both natural and man-made radioisotopes on (or in) the terrain surface in and around each of the nuclear related facilities. The measurement sensitivity and data processing procedures, coupled with total area coverage, provided both a broad overview and a detailed definition of the extent of gamma producing isotopes existing in the area. Specific areas containing radioactive sources producing gamma exposure rates of 1/2 μR/h or so at survey altitude (75m) were located; resulting radiation levels were defined and the responsible isotopes identified. Primary gamma producing isotopes found were ^{137}Cs, ^{60}Co, ^{234m}Pa, ^{208}Tl, ^{235}U, ^{214}Bi, and ^{40}K. Results are presented as radiation intensity isopleths superimposed on maps or photographs of the areas of interest. Related gamma energy spectral information is reported, together with a discussion of the location, activity and concentration of sources and contaminants in specific areas.

ACKNOWLEDGMENTS

Appreciation is given to L. J. Deal, Assistant Director of the U. S. Energy Research and Development Administration's Division of Operational Safety, for his support and encouragement in this survey project.

Both Wayne Hibbits and Jerry Wing of ERDA's Oak Ridge Office were very helpful in providing information on the facilities, in coordinating the operational aspects of the surveys, and in review of the report.

Acknowledgment is given to Larry Franks of EG&G Santa Barbara, and to Harold Beck of ERDA's Health and Safety Laboratory for a thorough review of the report.

Acknowledgment is also given for the excellent contribution of the EG&G field survey team: M. Sevart, T. Hess, I. Harris, G. Menkel, L. Arambula, and R. Lawson. Computer data reduction and analysis was carried out with the assistance of C. Bluitt, J. Jobst and J. Cates. R. Meibaum rendered photographic support. A. Fritzsche provided ground-based measurements.

CONTENTS

CONTENTS (Cont)

CONTENTS (Cont)

ILLUSTRATIONS

ILLUSTRATIONS (CON'T)

TABLES

1. SUMMARY

Airborne radiological surveys of the area surrounding ERDA's Oak Ridge facilities were made in September 1973 and again in November 1974. The surveys consisted of airborne measurements of gamma radiation from both natural and man-made radioisotopes on (or in) the terrain surface in and around each of the nuclear-related facilities. The measurement sensitivity and data processing procedures, coupled with total area coverage, provided both a broad overview and a detailed definition of the extent of gamma-producing isotopes existing in the area. Specific areas containing radioactive sources producing gamma exposure rates of 1/2 μR/h at survey altitude (75m) were located; resulting radiation levels were defined and the responsible isotopes identified. Primary gamma producing isotopes found were ^{137}Cs, ^{60}Co, ^{234m}Pa, ^{208}Tl, ^{235}U, ^{214}Bi, and ^{40}K. Results are presented as radiation intensity isopleths superimposed on maps or photographs of the areas of interest.

The natural radiation levels in the Oak Ridge vicinity generally vary from 6 to 10 μR/h, one meter above the ground, including a cosmic ray component of 3.8 μR/h. Higher levels were found over areas containing outcroppings of Chattanooga shale and over areas containing large quantities of coal cinders from power plants.

Detected radiation from man-made radioisotopes produced by operations at ERDA's Oak Ridge facilities can be grouped in four categories as follows:

(1) Radioactivity used in connection with each plant's activities.

These included the uranium sources located at the K-25 and Y-12 plants, the thorium sources located at the Y-12 plant and the x-ray, ^{137}Cs and ^{60}Co sources (including reactors) located in the buildings and immediate vicinity of the X-10 and Y-12 plants.

(2) Radioactivity from waste storage and burial grounds. This included activity from the White Wing Scrap Yard near K-25, the Y-12 burial ground, and several other burial grounds, low and intermediate level waste holding ponds and storage areas near X-10. This category also includes the White Oak Creek and White Oak Lake drainage basin near X-10 which contains radioactivity primarily resulting from Oak Ridge National Laboratory discharges in the early years of the atomic energy program.

(3) Radioactivity from ecology irradiation areas. Radioactivity is used to study radiation plant damage and as tracers in basic ecological research. These included two sources at Y-12, two areas on Chestnut Ridge, an area near the HPRR facilities and an area on ERDA property opposite Jones Island. Source activities from ^{60}Co and/or ^{137}Cs, derived from the aerial survey data, compared well with total activity existing in each area, indicating that the sources have remained at or near the surface.

(4) Contamination in the streams and river banks. Contamination from ^{137}Cs was detected in the mud banks and islands in the Clinch River downstream from White Oak Lake. Over a period of years, some radioactivity has escaped from White Oak Lake into the Clinch River and has accumulated in stream sediments. During the helicopter survey, the water level was low, revealing mud banks not normally seen. Average exposure rates 1m above the ground, derived from only man-made radiation as detected by the helicopter surveys, ranged from below one to about 5 $\mu R/h$ over these mud banks and islands . No detectable contamination was observed in the Clinch River banks beyond about 8 km down river from the K-25 plant site.

A small amount of radioactivity was detected in East Fork Poplar Creek. Elevated thorium concentrations were probably a result of long-term low-level discharge from the Y-12 plant. The ^{137}Cs contamination was attributed to worldwide fallout, accumulated over a period of years. The Oak Ridge water treatment plant takes water from the Clinch River (upstream from White Oak Creek) at the rate of 20 million gallons per day, purifies it, and then discharges the residue into East Fork Poplar Creek. Most of the worldwide fallout particulates are removed during the treatment process and then actually concentrated in the residue put into the creek.

The same process occurred at the sanitary water treatment plant for K-25. This plant takes water from the river (slightly contaminated from White Oak Creek drainage) at the rate of 5 million gallons per day and discharges its residue into a small stream near the plant. The contamination in this stream was highly visible in the airborne survey results. The exposure rates near the stream banks were 15 to 30 $\mu R/h$ from the contamination. The exposure rates from ^{137}Cs in East Poplar Creek was about 1 to 2 $\mu R/h$.

The exposure rates 1m above the ground shown in the isopleth maps are based on aerial measurements at 45 to 150m altitude. The resulting values represent averages over the 300 to 600m diameter circles of investigation. These averages are likely to differ from ground-based measurements made at specific locations because most of the sources are limited in extent and are non-uniform in distribution.

The detector sensitivity and spatial resolution of this survey provided reasonable assurance that any change in radiation levels significantly above background, arising from man-made or natural sources, were detected. The level of detectability (for 75m altitude surveys) for unshielded point sources on the ground surface was about 2 mCi of ^{60}Co or 6 mCi of ^{137}Cs. For equivalent 1m exposure rates (averaged over the detector field of view) resulting from man-made sources, the level of detectability was about 0.8 μR/h.

The results provide a broad overview of the location and identification of gamma-producing radioactive contaminants, their concentrations and spatial distributions, attributable to ERDA operations in the Oak Ridge area. Of particular value is the definition of radioactivity in areas difficult to measure by ground survey techniques. These results can be used in planning ground-based sampling and measurement programs for effective management and control of these radioisotopes. This survey has assisted ERDA in assessing the impact of its operations on the environment.

2. INTRODUCTION

The U. S. Energy Research and Development Administration (ERDA) maintains a continuing program* to determine the nature and quantities of radioactivity discharged to the environment from its own facilities which have potential health and safety or environmental significance.[1] The objectives of this program are to assure effective management and control of effluents (as well as reduction of the quantity of contaminants) and to assess the impact of its own operations on the environment.

As a part of this surveillance and assessment program, two airborne radiation surveys, one in September 1973 and one in November 1974, were made over the ERDA's Oak Ridge Facilities and surrounding area. The surveys, utilizing the Aerial Radiological Measuring System (ARMS), operated for the ERDA by EG&G, consisted of airborne gamma radiation measurements from both natural and man-made isotopes on or in the terrain surface. These surveys were a part of a continuing nationwide ARMS program, started in 1958 by the Division of Biology and Medicine of the Atomic Energy Commission, to monitor radiation levels in and around facilities producing, utilizing, or storing radioactive materials.

ERDA's Oak Ridge Reservation is located in Tennessee and contains three major operating facilities: The Oak Ridge National Laboratory (ORNL, X-10 area), the Oak Ridge Gaseous Diffusion Plant (ORGDP, K-25 area), and the Y-12 Plant, all operated by the Nuclear Division of Union Carbide Corporation. Other smaller facilities, utilizing nuclear materials, are also located within the area.

The ERDA-owned area, about 150 km^2, is bounded on the south and west by the Clinch River and generally on the north and east by a fence line shown in Figure 1.

The Oak Ridge National Laboratory (ORNL) is a large laboratory facility dedicated to research and development and production services in energy related fields. The Laboratory's facilities consist of nuclear

*Initiated by the U. S. Atomic Energy Commission (USAEC), parts of which were incorporated into ERDA in January 1975.

ORNL—DWG. 64-3713 R1

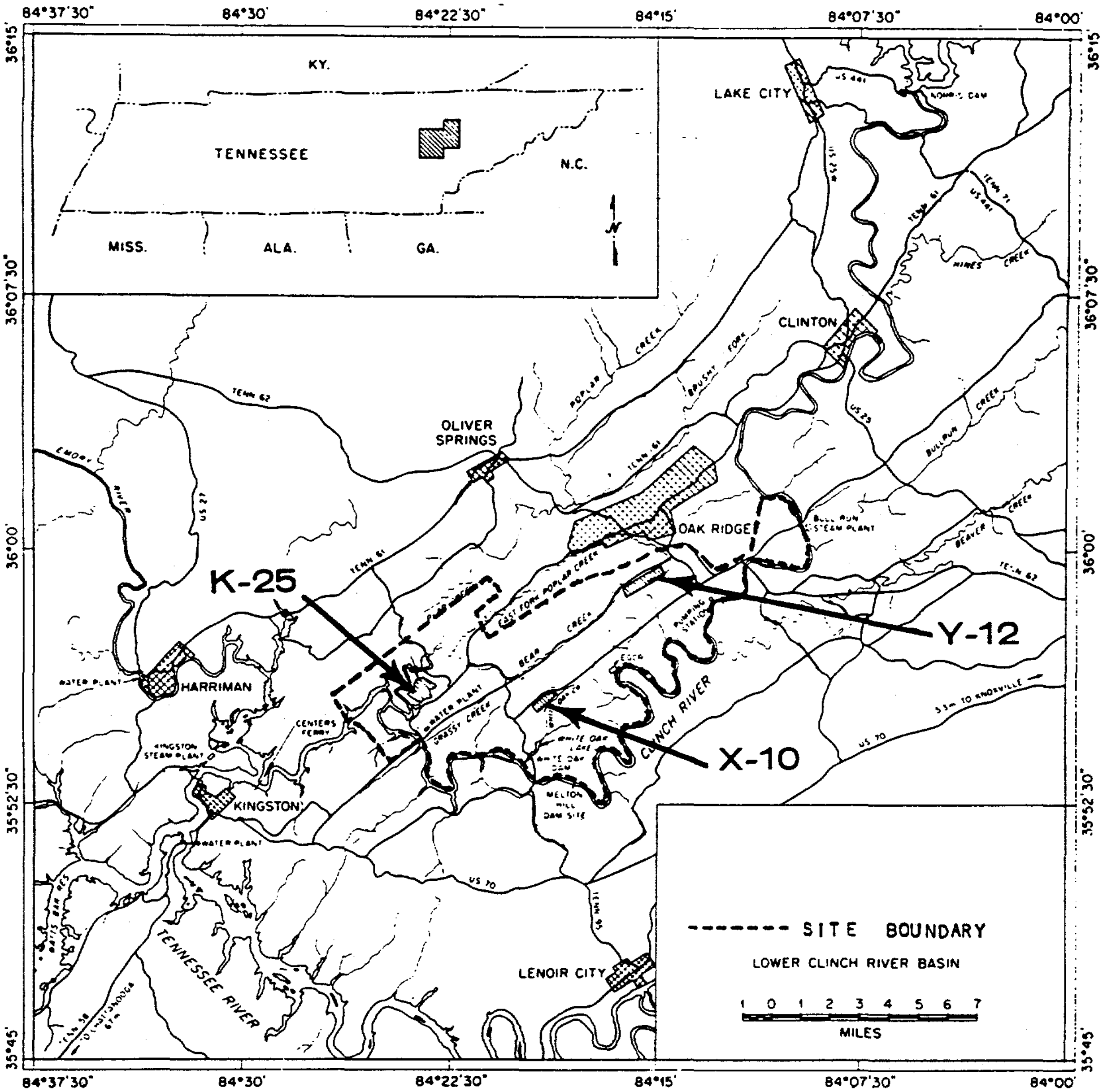


Figure 1. ERDA's Oak Ridge Facilities

reactors, chemical pilot plants, research laboratories, radioisotope production laboratories, and support facilities.[2] Low level discharges, primarily in the early years of the atomic energy program, have resulted in contaminants in the White Oak Creek and White Oak Lake areas. Many burial grounds also exist in the vicinity of the Laboratory.

The Oak Ridge Gaseous Diffusion Plant's primary mission is the enrichment of uranium hexafluoride in the ^{235}U isotope. This large industrial facility consists of 70 buildings used in production, research and development.

The Oak Ridge Y-12 Plant performs four major functions[2]: (1) production of nuclear weapon components, (2) fabrication support for weapon design agencies, (3) support for the Oak Ridge National Laboratory, and (4) support and assistance to other government agencies. A small amount of waste from this plant is discharged in East Fork Poplar Creek.

The multiplicity of operations of the Oak Ridge Facilities result in several categories of surface, man produced, gamma radiation observable from the air:

1. Radioactivity used in connection with the Plants' activities. This includes the thorium, and the depleted, natural and enriched uranium sources at the Y-12 and ORGDP Plants and the use of radioactive sources (including reactors) in the buildings and immediate vicinity of the ORNL and Y-12 Plants.

2. Radioactivity from waste storage and burial grounds. There are about 10 such areas located in and near the major facilities.

3. Radioactivity from ecology irradiation areas. Radioactivity is used to study radiation plant damage and as tracers in basic ecological research. Sixteen such areas have been used on the Oak Ridge Reservation.

4. Radioactivity from contaminated areas due to process water discharged directly into the streams or indirectly by drainage (or seepage) from or through waste storage, burial grounds or ecology irradiation areas.

The general purpose of the airborne surveys (ARMS program) of major ERDA national laboratories and nuclear facilities is to provide data to assist ERDA in identifying any radioactive contaminants, their concentrations and spatial distributions, attributable to ERDA operations. These results provide data to assist them in effective management and control of all radioisotopes at each site. The measurement sensitivity and data processing procedures provided by ARMS, coupled with total area coverage, provides both a broad overview and a detailed definition of the extent of gamma producing isotopes in specific areas. These results support the laboratories and facilities in assessing the environmental impact of their operations.

The specific objectives of the airborne surveys of the Oak Ridge area were:

1. To measure natural terrestrial radiation levels (on a broad basis) of an area surrounding and including the Oak Ridge ERDA site.

2. To detect and define the extent of any man-made gamma radiation existing in areas difficult to measure by ground based surveys.

3. To define the extent of gamma radiation in known areas.

4. To measure natural terrestrial radiation levels on a detailed basis at the new Clinch River Breeder Reactor site and other designated areas.

The data obtained as a part of the first objective would be used as a basis for repeat surveys in case of an accident or incident in which any radioactivity is released into the environment (large-scale deposition). These data were gathered on the fixed-wing survey conducted in September 1973. The aircraft was flown at speeds ranging from 60 to 75m per second, 150m above the ground, along flight lines spaced from 0.4 to 1.6 km apart. This survey covered the entire Oak Ridge Reservation, as well as an area off-site extending approximately 8 km on each side of the site boundaries. A similar survey[3] had been done in 1959, covering an area about 160 km by 160 km. The results from Ref. 3 were used as guidelines for planning this survey (September 1973), particularly as pertaining to geologic features.

The other objectives were met by utilizing a helicopter platform in order to survey at lower altitudes (typically 75m) and at slower speeds (typically 30 to 40m per second). The helicopter survey, conducted in November 1974, was used to provide detailed coverage of selected areas in the Oak Ridge vicinity. Survey line spacings of 90m allowed for complete area coverage and provided a spatial resolution on the order of 75m.

3. SURVEY OPERATIONS AND DATA ANALYSIS

A brief discussion of data acquisition, analysis and application is included in this chapter. Details of the instrumentation used are described in Appendix A, survey operations in Appendix B, spectral results in Appendix C, and data analysis techniques in Appendix D.

3.1 Survey Operations

For the fixed-wing survey, the primary detector system consisted of three arrays, each containing seven 10-cm diameter by 10-cm thick NaI(Tl) detectors. For the helicopter survey, two pods, each containing twenty 12.7-cm diameter by 5-cm thick NaI(Tl) detectors, were mounted externally on a helicopter. A full gamma energy spectrum (from .05 to 3.0 MeV) was acquired and updated every three seconds. Supporting information was updated every 0.2 second. These data were stored on magnetic tape.

For the fixed-wing survey, flight lines previously laid out on a topographic map were flown using visual navigation. The major flight lines, numbered 4 thru 16 and spaced 1.6 km apart, are shown in Fig. 2. More closely spaced lines, numbered 23 thru 57 spaced 0.4 km apart, were flown over the Oak Ridge Reservation itself. An inertial navigation system was used to determine the aircraft's position at all times.

Helicopter navigation was done visually with the aid of maps obtained from aerial photography. The survey consisted of approximately 180 flight lines ranging from 1.5 to 12 km in length at an altitude of 75m above the ground. A map showing designated areas for special emphasis is shown in Fig. 3. Actual survey lines flown are shown in Fig. 4. The areas to be surveyed by helicopter were chosen on the basis of the results of the airplane survey and upon the advice of ERDA's Oak Ridge Operations Office.

In addition to those designated areas shown in Fig. 3, the following surveys were made:

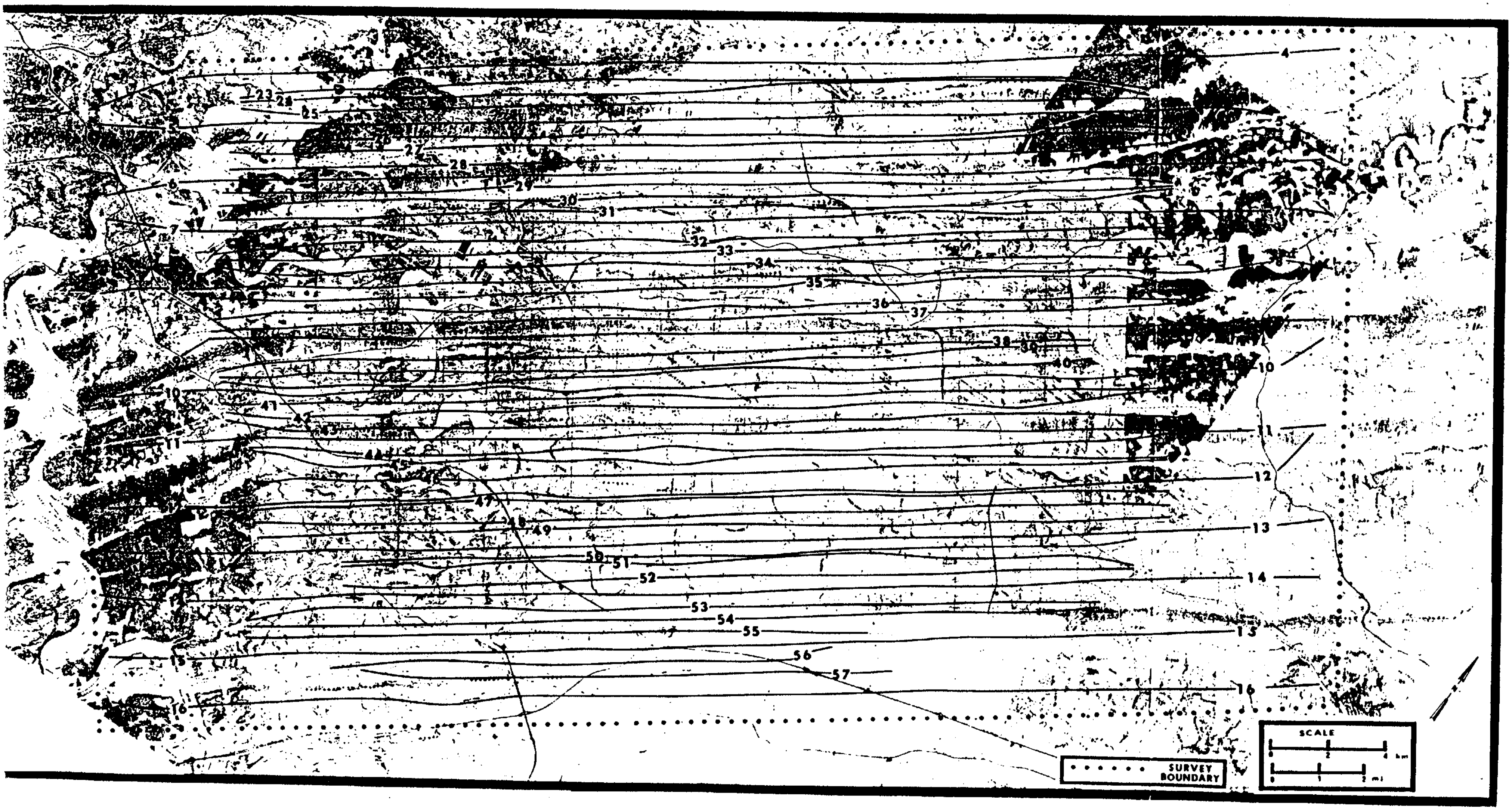


Figure 2. Survey flight lines for the airplane survey (September 1973) overlaid on a topographic map (Oak Ridge facilities).

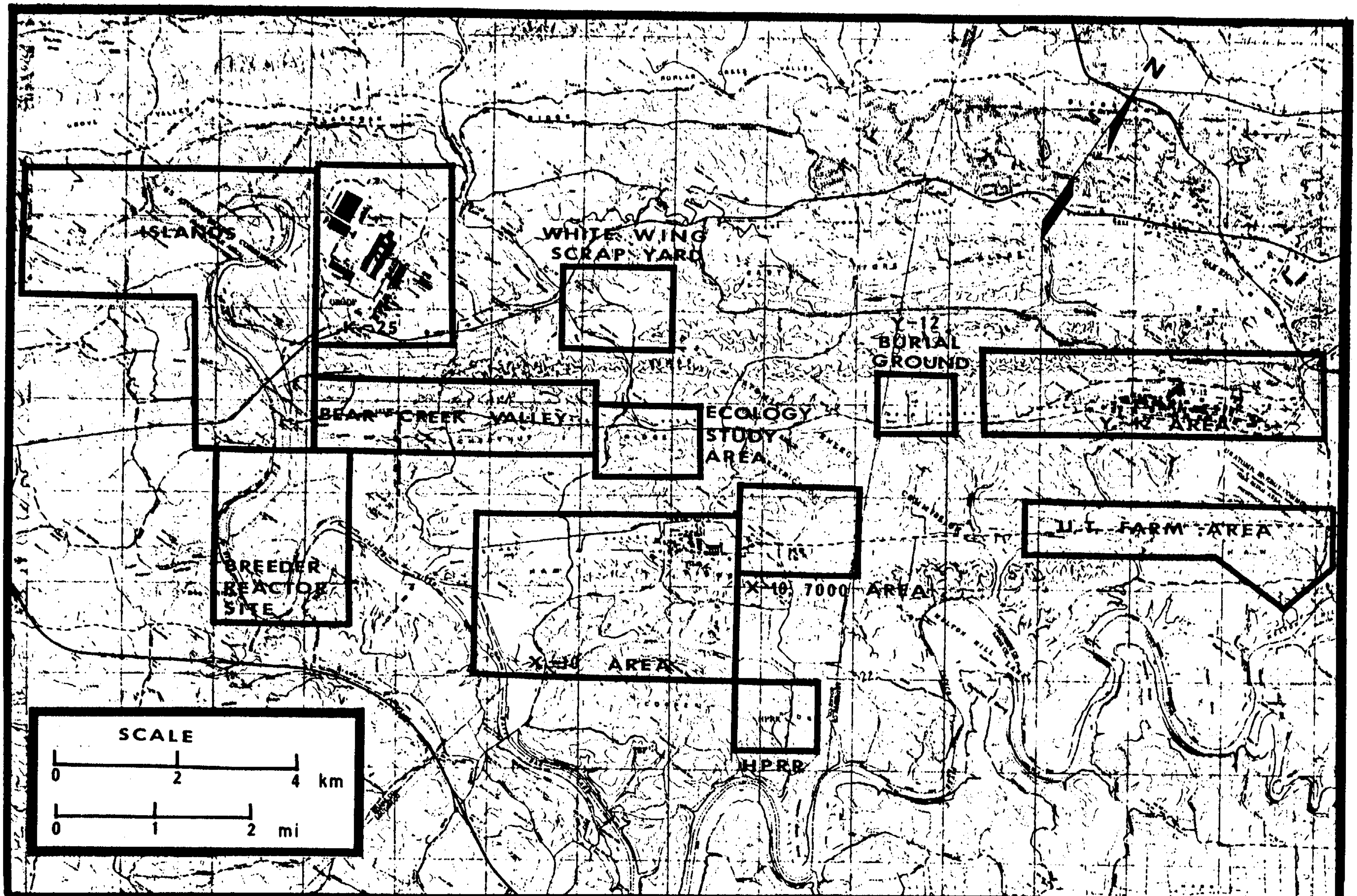


Figure 3. Special designated areas for helicopter surveys, Oak Ridge ERDA Site.

OAK RIDGE AREA

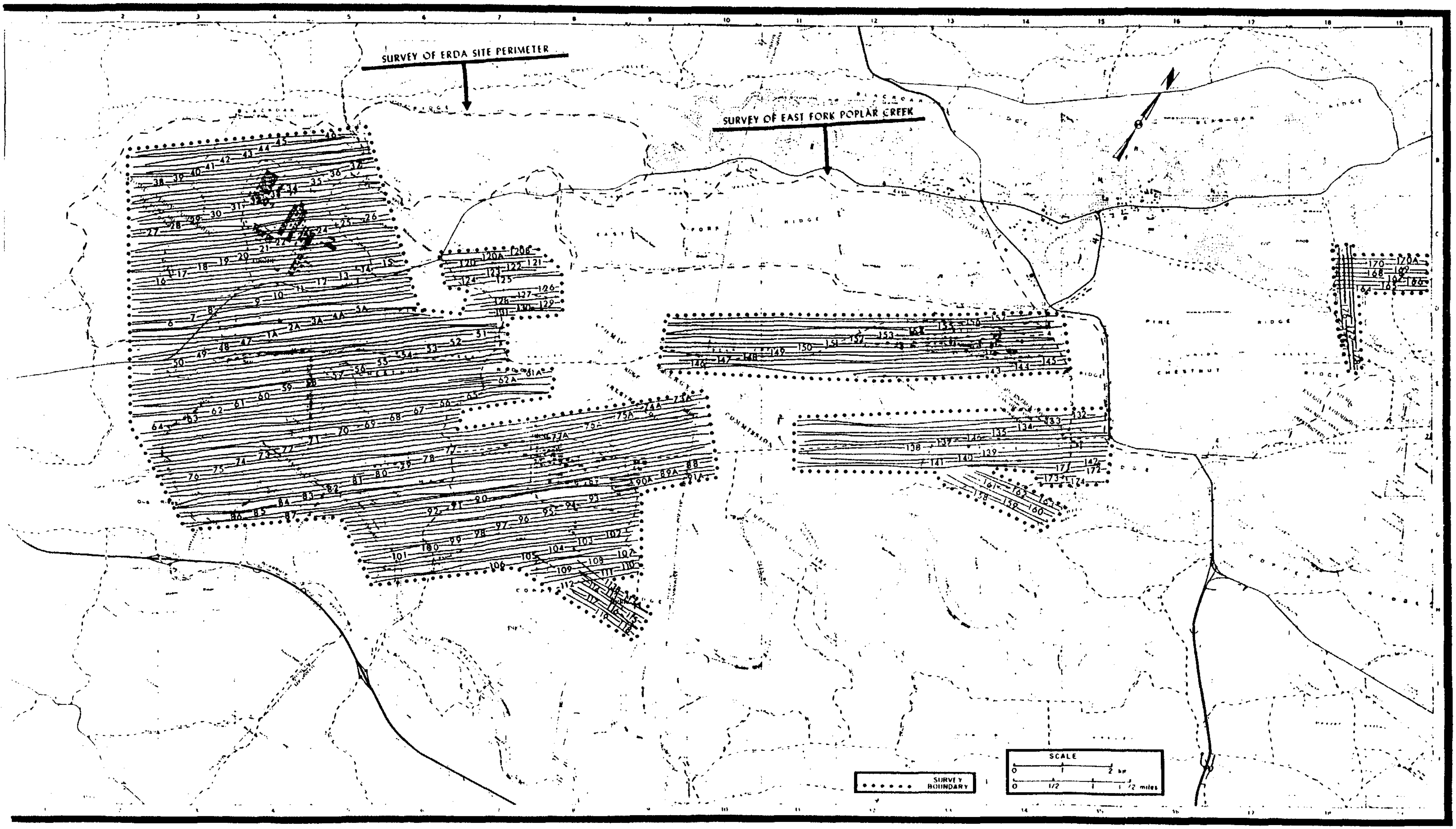


Figure 4. Actual helicopter survey lines for the Oak Ridge survey.

1. East Fork Poplar Creek from Y-12 to K-25. The survey altitude was 45m above the creek, except over populated areas where the altitude was 150m. (Shown in Fig. 4)

2. Bear Creek from Y-12 to K-25, 45m above the creek.

3. Both sides of the Clinch River, including sloughs, from East Oak Ridge (sewage disposal plant) to several km west of K-25; altitude was about 45m above the water's edge.

4. ERDA Reservation perimeter survey (north and east boundaries); altitude was 90m above the ground. (Shown in Fig. 4)

5. A small area east of the Oak Ridge Marina. (Shown in Fig. 4)

6. All of the area generally between the X-10 and K-25 Plants.

7. A detailed island and mud bank survey along the river from White Oak Creek to the intersection of the Clinch and Tennessee Rivers. Altitude was 45m above the water.

Using the 40 detectors in both pods, the gamma count rate over the X-10, White Oak Creek area exceeded a million counts per second. Spectral distortion, due to pulse pile-up, occurred when the count rate exceeded 50,000 cps. Therefore, most of this area (lines 77 thru 105) was resurveyed at an altitude of 100m using only two detectors. The combined results, then provided maximum detection sensitivity for the low radiation activity areas using the 40 detectors and good gamma spectral integrity over those areas of high activity using only two detectors.

A special low energy survey was conducted on November 20, 1974. The multichannel analyzer was set at 1 keV per channel (maximum energy 300 keV) and survey lines 120 thru 125 (White Wing Scrap Yard), 47 thru 58 (Bear Creek Valley) and every other line from 60 thru 84 (Clinch River Breeder Reactor Site) were repeated to search for the presence of ^{241}Am and/or ^{235}U. The first two sets of survey lines were flown at 45m altitude and the latter set at 75m.

The combined use of an inertial navigation system and a microwave ranging system provided accurate aircraft position data at any point in time along a survey line.

The data on the magnetic tapes were processed on a mini-computer located in a mobile data processing laboratory. A large variety of software routines and supporting equipment were available for detailed analysis of the data. Some of the data were processed during the helicopter survey to assure data acquisition integrity and to provide preliminary results as soon as possible. Instrumentation used and survey operation details are given in Appendices A and B.

3.2 Data Analysis

3.2.1 Natural Terrestrial Radiation Levels

It was of interest to estimate the exposure rates 1m above the ground from natural radioisotopes existing in the soil. Contributions from worldwide fallout (mostly ^{137}Cs) were also included in this category.

For the fixed-wing survey corrections were made for live time, non-terrestrial background contributions and altitude deviations. The resulting "net" count rate (0.05 to 3.0 MeV) was divided into letter categories and plotted on a map versus aircraft position so that gamma intensity isopleths could be drawn. Applicable 1m exposure rates were then assigned to each letter category (see Appendix D).

For the helicopter survey, the same procedures were followed for the gross count (0.05 to 3.0 MeV). In addition, the net count over the upper energy spectrum (1.40 to 3.0 MeV) was determined and plotted in appropriate letter categories. The latter provided an estimate of the natural terrestrial radiation levels in those areas containing man-made radiation.

3.2.2 Radiation Levels from Man-Made Radioisotopes

It was desirable to separate the spectral contributions due to natural radioisotopes from those contributed by man-made radiation in order to determine the location, magnitude and type of gamma radio-activity in the area surveyed. A stripping analysis technique was used to extract the contributions of the individual man-made radioisotopes from the complex spectra. (See Appendix D)

One of the most important results of the ARMS surveys has been the extraction of the total count rate (relative to the total photon flux density) contributed only by man-made radiation. This term has been designated man-made gross counts (MMGC). The spectral extraction process allows the detection of low levels (<1 μR/h) of man-made radiation in the presence of subtle variations in the natural background.

The isotopes of primary interest detected during the airborne surveys were ^{208}Tl, ^{60}Co, ^{137}Cs, and ^{234m}Pa.* The photopeak count rates for each isotope were extracted separately from the spectral data, divided into appropriate categories, and assigned a radiation intensity code letter. Radiation intensity isopleths were constructed by plotting, on a second-by-second basis, the radiation data as a function of position after the position information was properly scaled for the particular map desired.

3.3 Application to Surface Situations

Ionization in air is a common measure of the gamma radiation levels at a given location. It has been useful to relate the airborne measurements to an equivalent exposure rate 1m above the ground. The gamma count rates at altitude (gross counts and/or photopeak count rates) were converted to an equivalent 1m exposure rate by appropriate conversion factors derived from calibration experiments (see Appendix D). The resulting exposure rates represent averages over the entire area sampled by the airborne detectors (300 to 600m in diameter). These averages are likely to differ from ground-based measurements made at specific locations (particularly for man-made radiation) because most of the sources are limited in extent and are non-uniform in distribution. However, criteria for making comparisons and their limitations are discussed in detail in Appendix D.

*^{234m}Pa is a natural decay product of ^{238}U, but is grouped with man-made radioelements, because detecting its presence indicates man has extracted and brought together large quantities of elemental uranium out of its natural setting.

4. RESULTS

The primary results of the airborne radiological survey of the Oak Ridge site are presented as radiation intensity isopleths on maps and photographs of the areas of interest. An overview of the entire reservation and vicinity is given first. Details of specific areas follow.

Ground level exposure rates, isotope activities and/or concentrations are inferred from the airborne results. The detectors used were very sensitive, detecting fractions of the natural radiation levels. Very low levels (<1 μR/h) of man-made radiation were detected as can be seen in the results. These levels, even the relatively high levels as detected, should not automatically imply a radiological hazard. For example, the highest level reached (over the White Oak Creek area) was about 1 million gamma counts per second (about an mR/h). A person would have to remain at that location several hours for an ordinary film badge to detect a radiation exposure. Many of the radiation intensities from man-made isotopes indicate levels less than the natural radiation intensities in the same area.

4.1 Oak Ridge Reservation

4.1.1 Natural Background Levels

The natural terrestrial radiation levels for the Oak Ridge Reservation and vicinity are given in Fig. 5. These were obtained from the combined results of the airplane and helicopter surveys. The exposure rates are applicable to 1m above the ground as averages over the entire circle of investigation (400 to 600m in diameter). With this qualification, the values are probably accurate to ± 30%. A few 1m measurements at specific locations compare well with the airborne results as indicated in Appendix E.

Most of the radiation levels are relatively low (2 to 5 μR/h). Gamma radiation from only terrestrial sources are given. The exposure rate from cosmic radiation is about 3.8 μR/h.

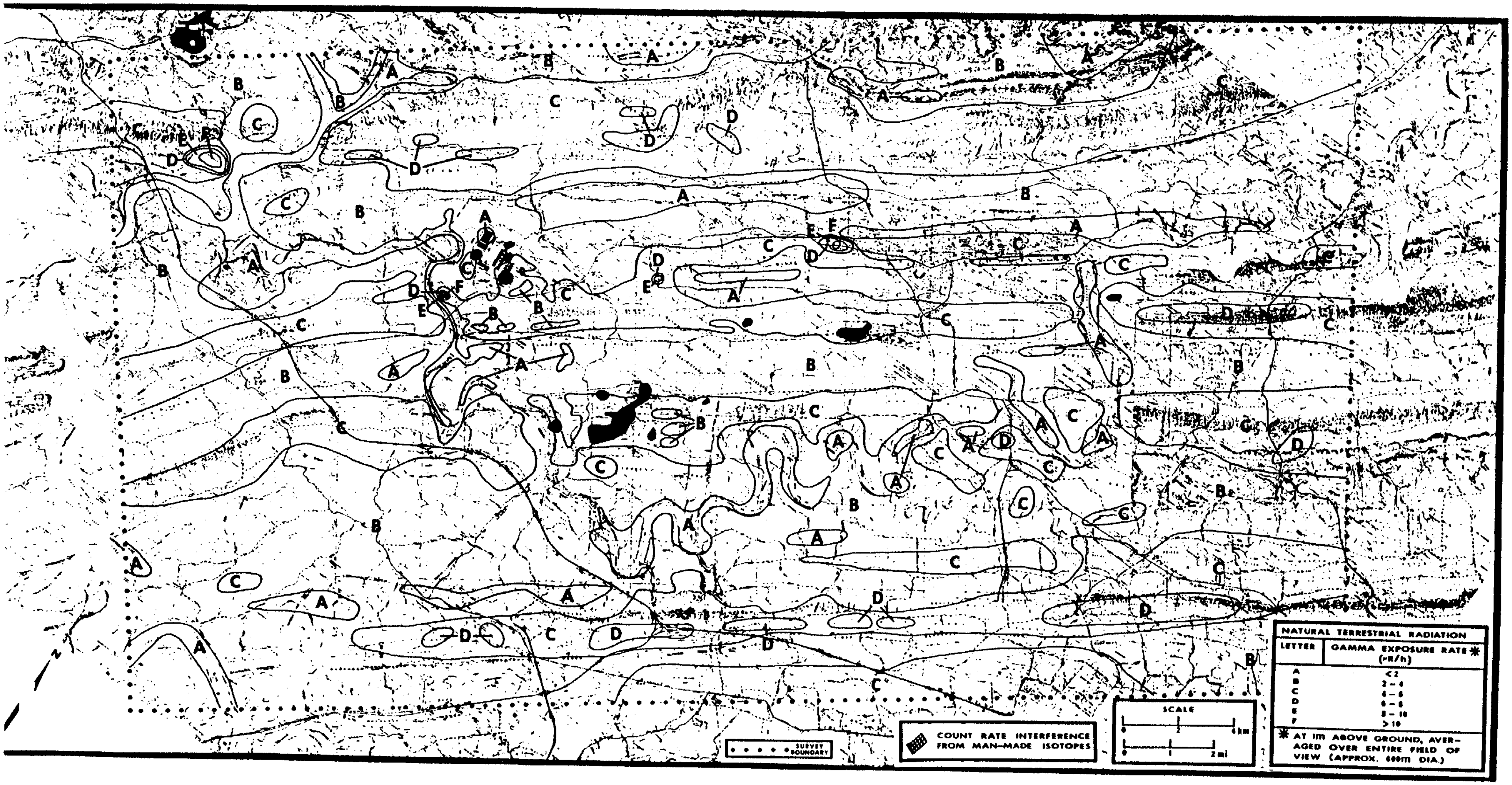


Figure 5. Natural terrestrial radiation exposure rate levels 1m above the ground inferred from airborne surveys of ERDA's Oak Ridge Reservation and vicinity. Survey date: Sept. 1973 and Nov. 1974. For total background radiation levels, an exposure rate of 3.8 $\mu R/h$ should be added to account for cosmic radiation contributions.

Four locations having higher than normal levels were observed. A cinder pile near K-25 indicated average levels of more than 10 μR/h (letter category F). Survey meter measurements 1m above the center of the pile indicated 20 to 30 μR/h. The cinders were coal tailings from an old power plant.

An area, north of Kingston (upper left of Fig. 5), near the fossil fuel power plant also indicated average levels of more than 10 μR/h. The area seems to be centered over the large sludge areas which may also be due to tailings from the existing power plant.

A small amount of outcropping of Chattanooga Shale, rich in uranium, exists on East Fork and Pine Ridges. The data taken during the helicopter survey of the ERDA Reservation boundary showed high natural radiation levels near the top of East Fork Ridge (about 6 km northeast of K-25). Average levels of 8 to 10 μR/h (letter E) were indicated. Survey meter measurements over similar outcroppings only a few meters across indicated levels up to 30 μR/h. A plot of the 1.76 ^{214}Bi photopeak versus time is shown in Fig. 6 to illustrate the probable location of the outcropping.

A small area near East Fork Poplar Creek just west of Oak Ridge also indicated average levels greater than 10 μR/h. This is probably the result of thorium wastes from Y-12 accumulating on a flood plain.

4.1.2 Man-Made Radiation Levels

The fixed wing survey data for man-made radiation levels are not presented in this report, because all of the areas containing man-made radioactivity were also surveyed by helicopter. The helicopter survey data were processed to extract gross count rates contributed only by man-made isotopes emitting gamma rays of energies less than 1.4 MeV. The resulting man-made gross count (MMGC) isopleth is shown in Fig. 7. The results are given as equivalent, average 1m exposure rates to show the order of magnitude of radiation levels contributed by man-made radiation. The actual levels at specific locations will vary considerably because all the sources are limited in extent and are likely to be non-uniform in distribution.

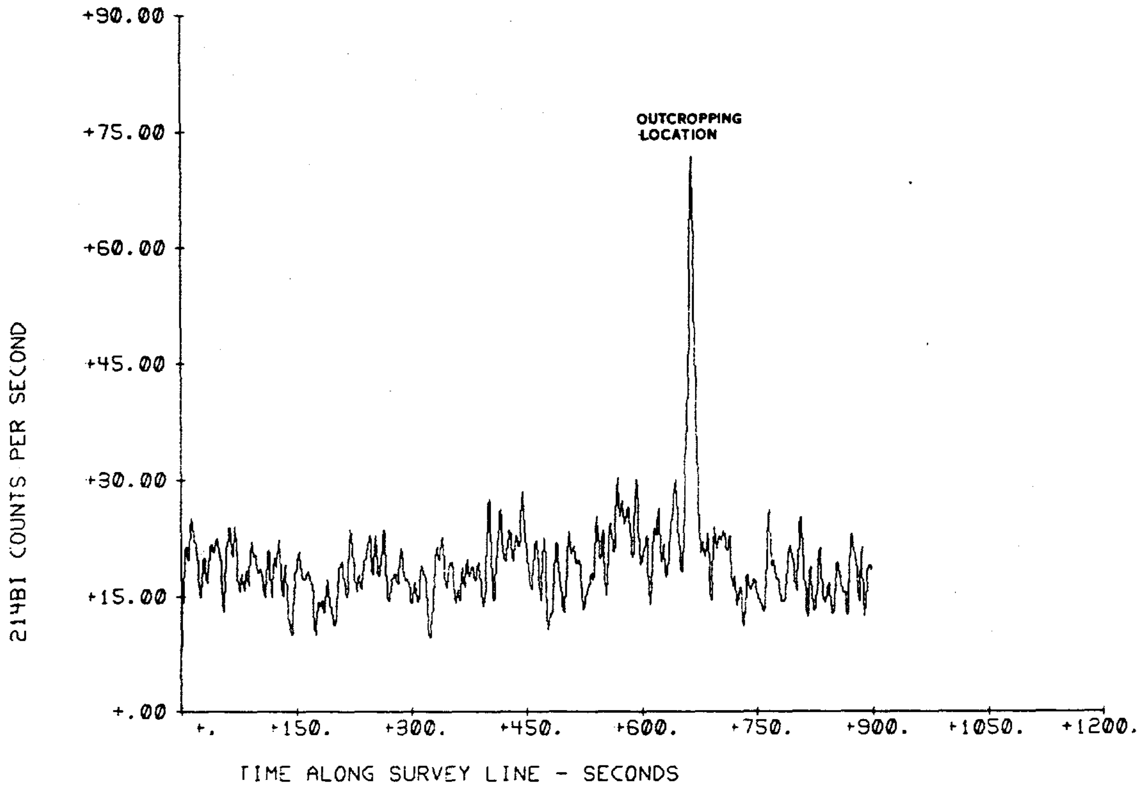


Figure 6. Counts per second in ^{214}Bi photopeak (1.76 MeV) along ERDA boundary survey line, showing location of Chattanooga shale outcropping.

OAK RIDGE AREA

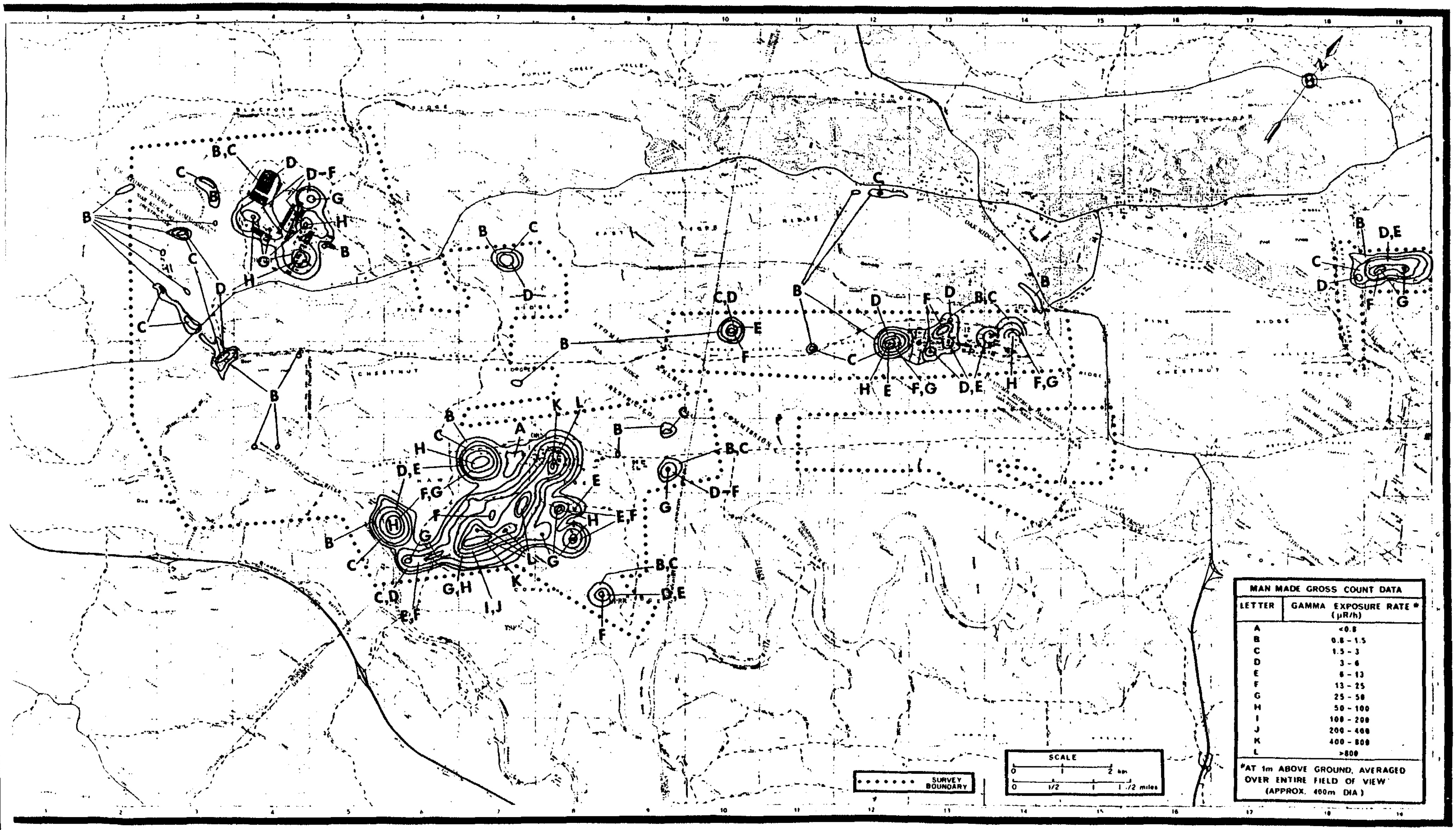


Figure 7. Radiation levels resulting from only man-made radiation, inferred from helicopter survey data taken at 75m altitude, Nov. 1974, over ERDA's Oak Ridge Reservation and vicinity. Natural radiation levels are from 5 to 10 μR/h (includes cosmic radiation).

As is described in Appendix D, a B level represents MMGC rates from 900 to 1800 cps, a C level from 1801 to 3600 cps, etc. A conversion factor of 1170 cps at 75m per μR/h at 1m was applied to all the data.

The data processing procedures provided good sensitivity to man-made radiation. Areas where equivalent, average 1m exposure rates as low as 1 μR/h existed were reliably defined. The results given in Fig. 7 provide an overview of the man-made gamma radiation conditions existing (in November 1974) in the Oak Ridge vicinity. The details of each area are discussed in Section 4.2.

4.1.3 Isotope Isopleths

Gamma radiation intensity isopleths derived from photopeak count rates from ^{137}Cs, ^{60}Co, and ^{234m}Pa isotopes are given in Figs. 8, 9, and 10, respectively. The conversion from photopeak count rates to flux densities and exposure rates are discussed in Appendix D. The equivalent average 1m exposure rates are based on an assumption of a radioisotope distribution which is an average between a surface distribution and a uniform (volume) soil distribution. The assumption is also made that the detector response is an average between an isotropic and cosine detector response. The actual 1m exposure rates will depend on both vertical and horizontal distribution of the isotope. The values are given simply as broad indicators of radiation intensities in units (exposure rates) easily recognizable.

4.2 Specific Areas

A more detailed examination of specific areas of interest was made and are presented in this section. Two areas, not associated with ERDA activities are discussed in Appendix F.

4.2.1 River, Islands, and Mud Banks

No man-made radiation was observable in the river bank surveys between the Oak Ridge Marina and White Oak Lake. Many mud banks were exposed in this area. These were carefully surveyed at an altitude of 45m. The detection system and processing procedures were sufficiently sensitive to detect sources producing exposure rates of 1/2 μR/h at 45m altitude. The corresponding apparent, point source activity required to produce 1/2 μR/h at 45m is about 1 mCi of ^{60}Co or 3 mCi of ^{137}Cs.

OAK RIDGE AREA

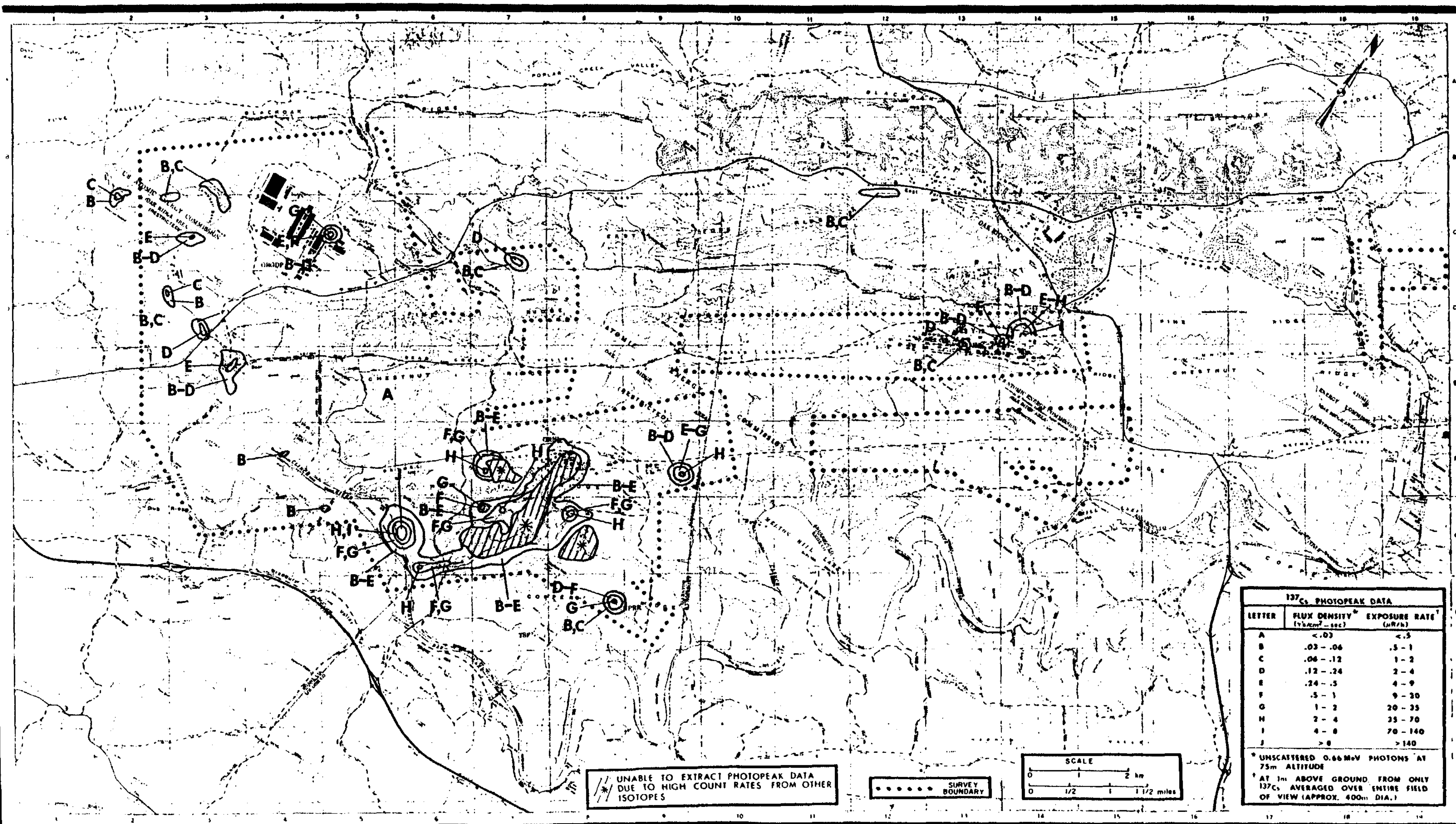
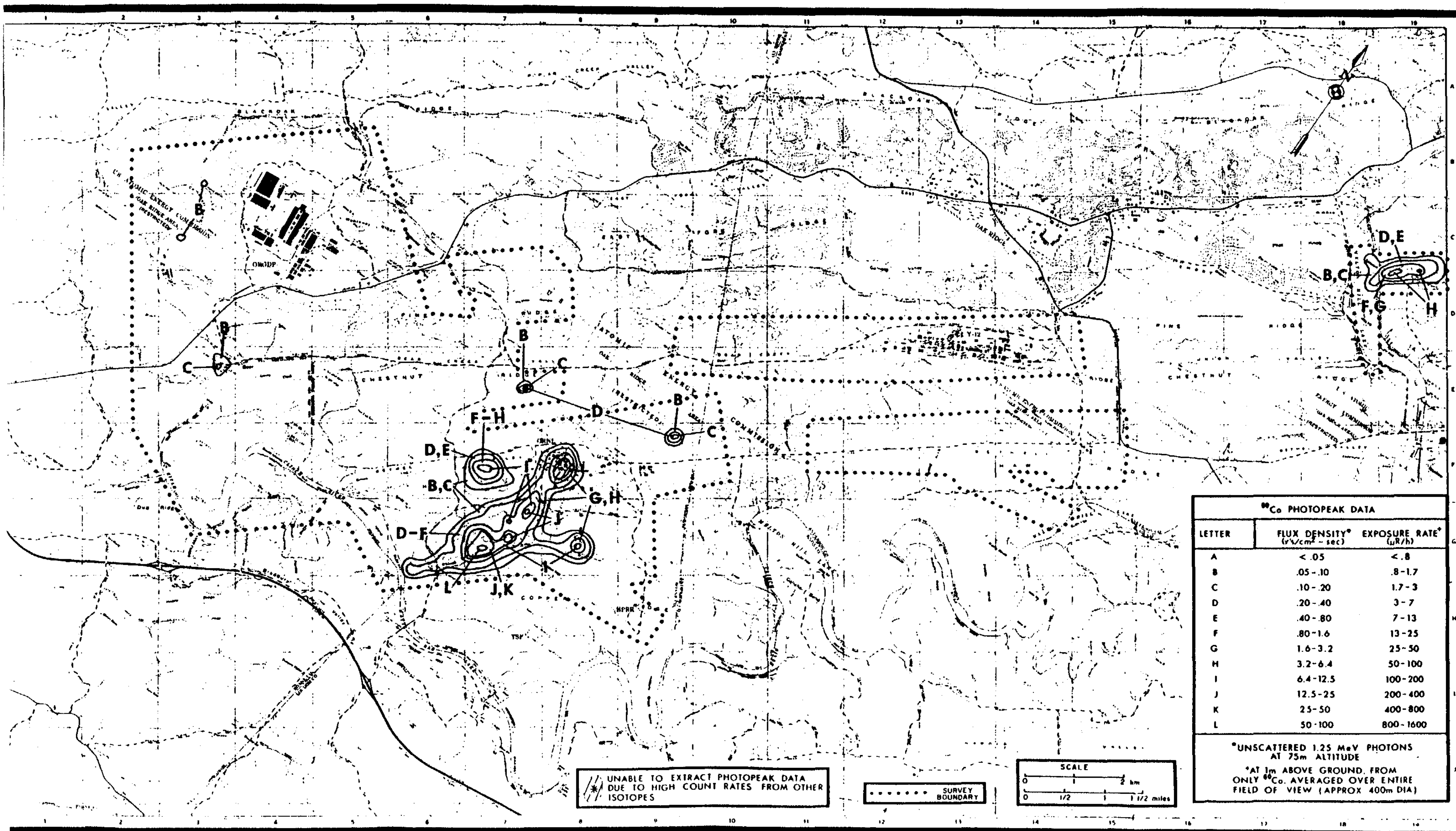


Figure 8. Photopeak (0.662 MeV) gamma flux densities at 75m and inferred exposure rates at 1m from ^{137}Cs existing on or in the surface. Derived from helicopter survey data, Nov. 1974, over ERDA's Oak Ridge Reservation and vicinity. Natural radiation levels vary from 5 to 10 μR/h (includes cosmic radiation).

OAK RIDGE AREA



^{60}Co PHOTOPEAK DATA		
LETTER	FLUX DENSITY* (γ's/cm^2 - sec)	EXPOSURE RATE† (μR/h)
A	< .05	< .8
B	.05 - .10	.8 - 1.7
C	.10 - .20	1.7 - 3
D	.20 - .40	3 - 7
E	.40 - .80	7 - 13
F	.80 - 1.6	13 - 25
G	1.6 - 3.2	25 - 50
H	3.2 - 6.4	50 - 100
I	6.4 - 12.5	100 - 200
J	12.5 - 25	200 - 400
K	25 - 50	400 - 800
L	50 - 100	800 - 1600

*UNSCATTERED 1.25 MeV PHOTONS AT 75m ALTITUDE

†AT 1m ABOVE GROUND, FROM ONLY ^{60}Co, AVERAGED OVER ENTIRE FIELD OF VIEW (APPROX 400m DIA)

Figure 9. Photopeak (1.25 MeV) gamma flux densities at 75m and inferred exposure rates at 1m from ^{60}Co existing on or in the surface. Derived from helicopter survey data, Nov. 1974, over ERDA's Oak Ridge Reservation and vicinity. Natural radiation levels vary from 5 to 10 μR/h (includes cosmic radiation).

OAK RIDGE AREA

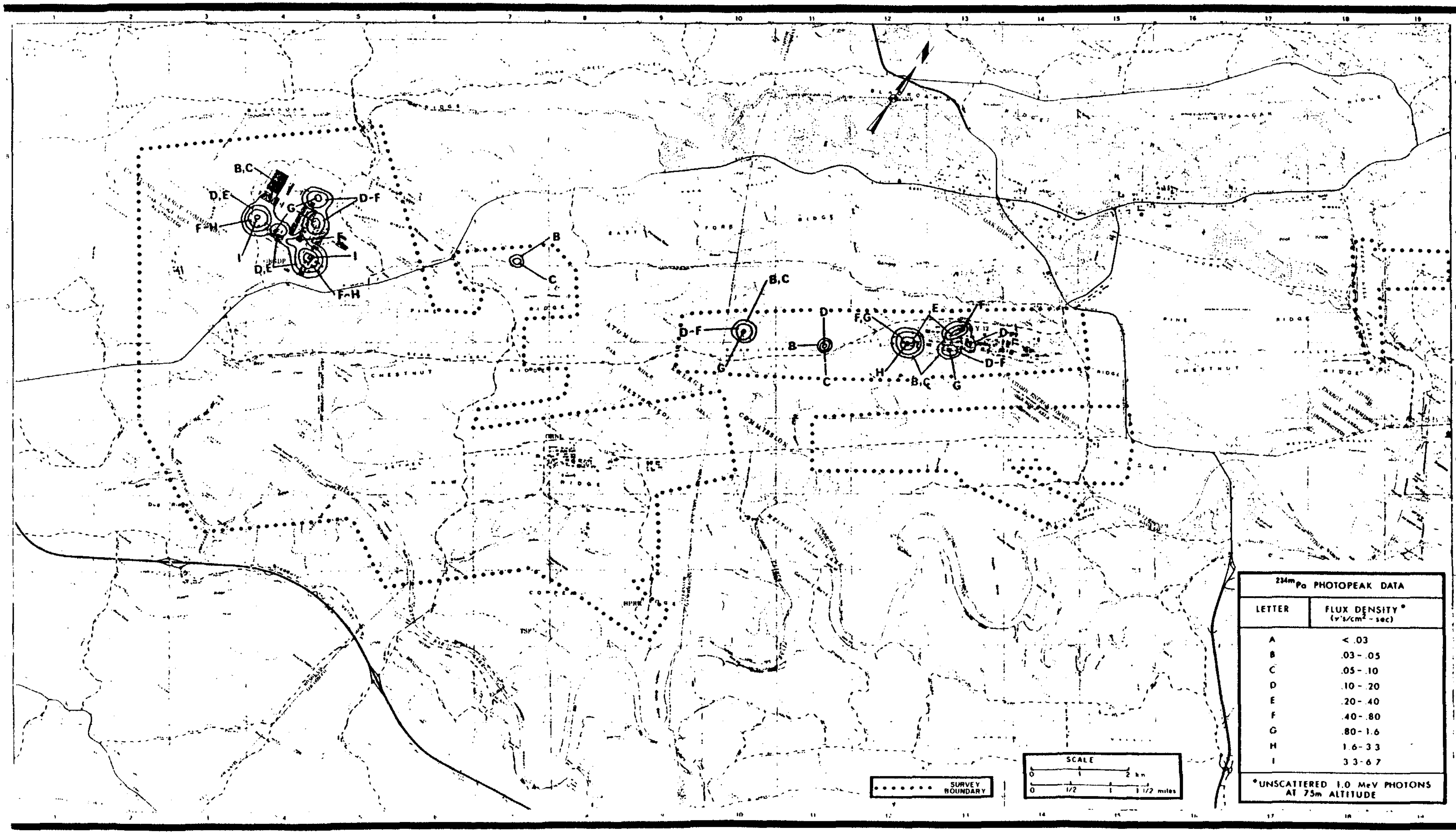


Figure 10. Photopeak (1.00 MeV) gamma flux densities at 75m altitude from ^{234m}Pa existing on or in the surface. Derived from helicopter survey data, Nov. 1974, over ERDA's Oak Ridge Reservation and vicinity. Natural radiation levels vary from 5 to 10 μR/h (includes cosmic radiation).

The survey down river from White Oak Lake did show the presence of man-made radioactivity, however. MMGC isopleths are shown in Fig. 11 and 12, and a ^{137}Cs isopleth in Fig. 13. The river was low (Watts Bar level at 224.8m above sea level), exposing mud banks and islands not normally seen.

Radiation count rates (due only to man-made isotopes) up to a D level were observed over several locations. A D level represents an average of about 2 to 5 $\mu R/h$ above the ground. From data presented in Appendix D, a closer approximation of exposure rates at specific locations can be inferred. For example, Brashear Island is about 100m wide. If one assumed uniform distribution on the surface and a reduction factor of 2 for ground roughness and terrain effects, a D level would represent on the order of 10 to 15 $\mu R/h$ 1m above the surface. In the real situation, higher levels are probably observable near the water's edge than in the center of the island. The Clinch River Study[4] indicates that ^{60}Co and ^{137}Cs in the river sediments could produce exposure rates 10 to 100 $\mu R/h$, if unattenuated by water. The exposure rate from natural radiation (including cosmic radiation) is about 5 to 10 $\mu R/h$ over these islands.

Another way of implying ground level information from the aerial data is to estimate the activity within a certain area. Since all the isopleths are closed, one can estimate the total apparent surface activity. The following total apparent surface activities for ^{137}Cs and ^{60}Co were estimated within the designated areas shown in Fig. 12.

Area	Apparent surface activity - mCi ^{60}Co	^{137}Cs
Water treatment plant area (I_1)	5 to 10	50 to 200
Area west of K-25 (I_2)	<5	30 to 100

The level of Watts Bar Lake varies by as much as 1.8m from winter to summer. Thus, during the summer when the lake level is high, radiation levels from man-made isotopes may not be observable.

As can be seen in the above table, the primary contaminant is ^{137}Cs with small amounts of ^{60}Co observable over some locations. Sample spectra are given in Spectrum Nos. 1, 2, and 3 in Appendix C. The locations of these spectra are shown in Fig. 11 and 12. The likely source of the contaminant is the drainage from White Oak Lake. As

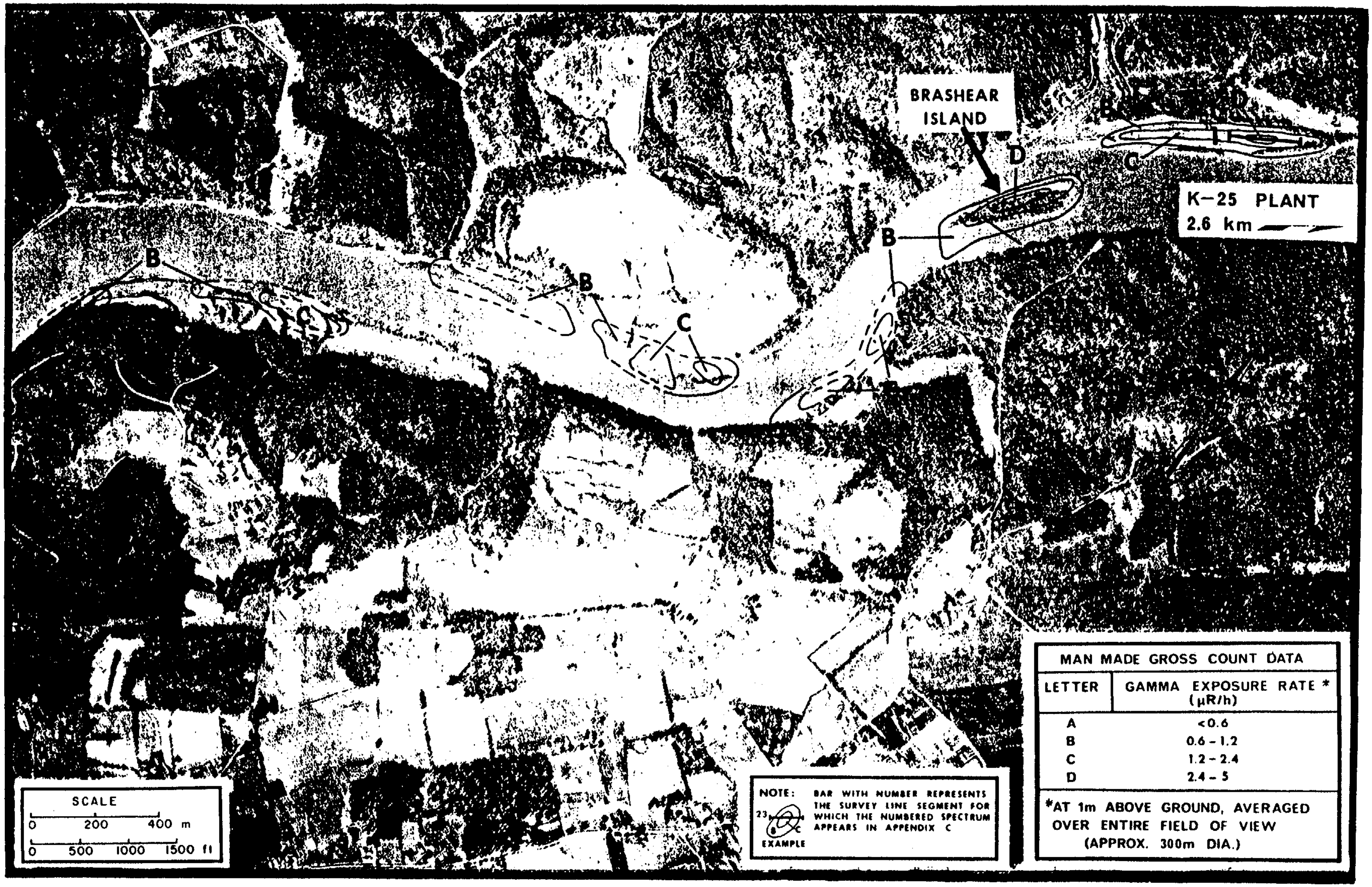


Figure 11. Radiation levels resulting from only man-made radioisotopes, inferred from helicopter survey data taken at 45m altitude, Nov 1974, of the river and islands west of K-25, Oak Ridge. Natural radiation levels vary from 5 to 10 $\mu R/h$ (includes cosmic radiation).

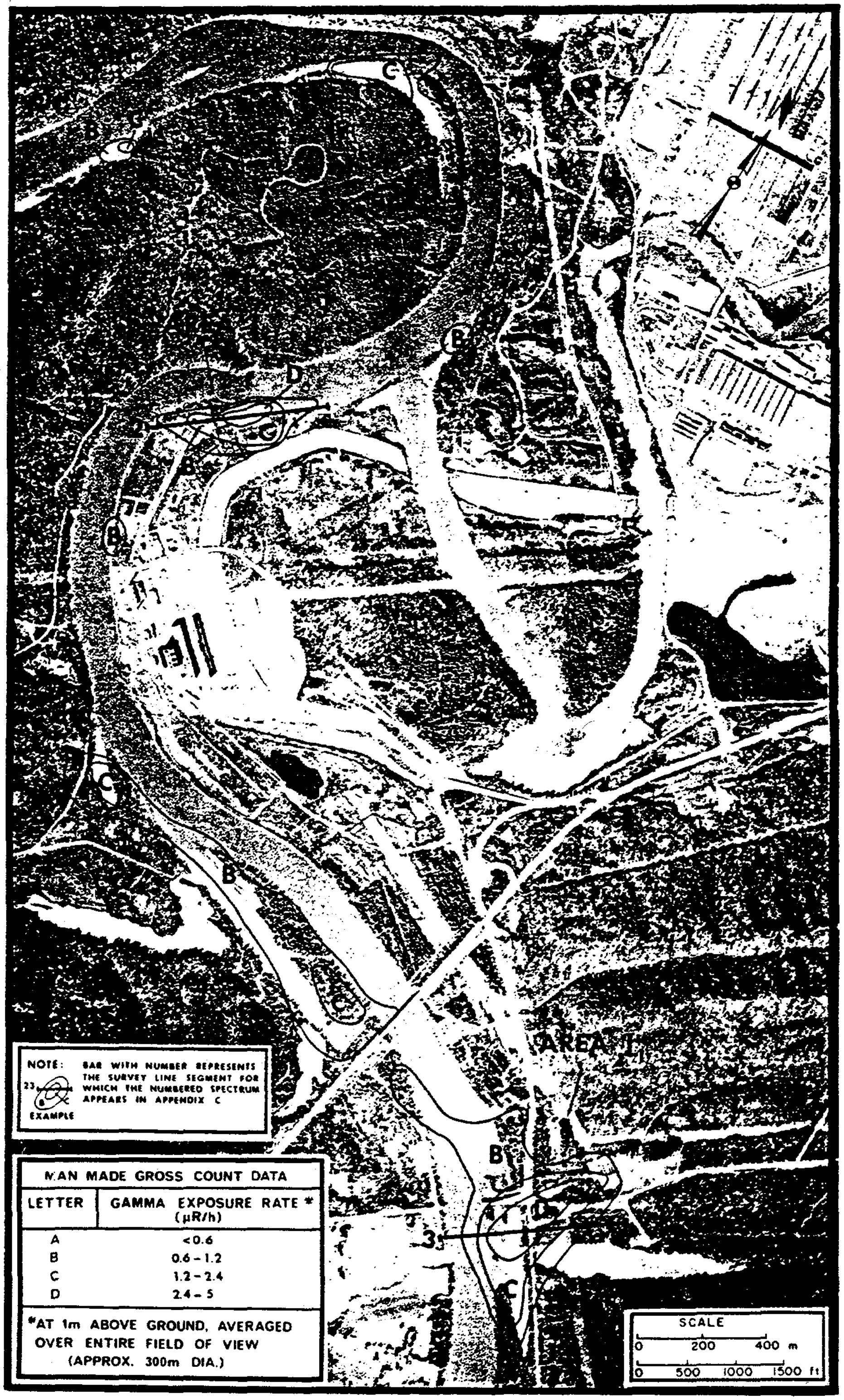


Figure 12. Radiation levels resulting from only man-made radioisotopes, inferred from helicopter survey data taken at 45m altitude, Nov 8, 1974, of the river and islands west and south of K-25, Oak Ridge. Natural radiation levels vary from 5 to 10 μR/h (includes cosmic radiation).

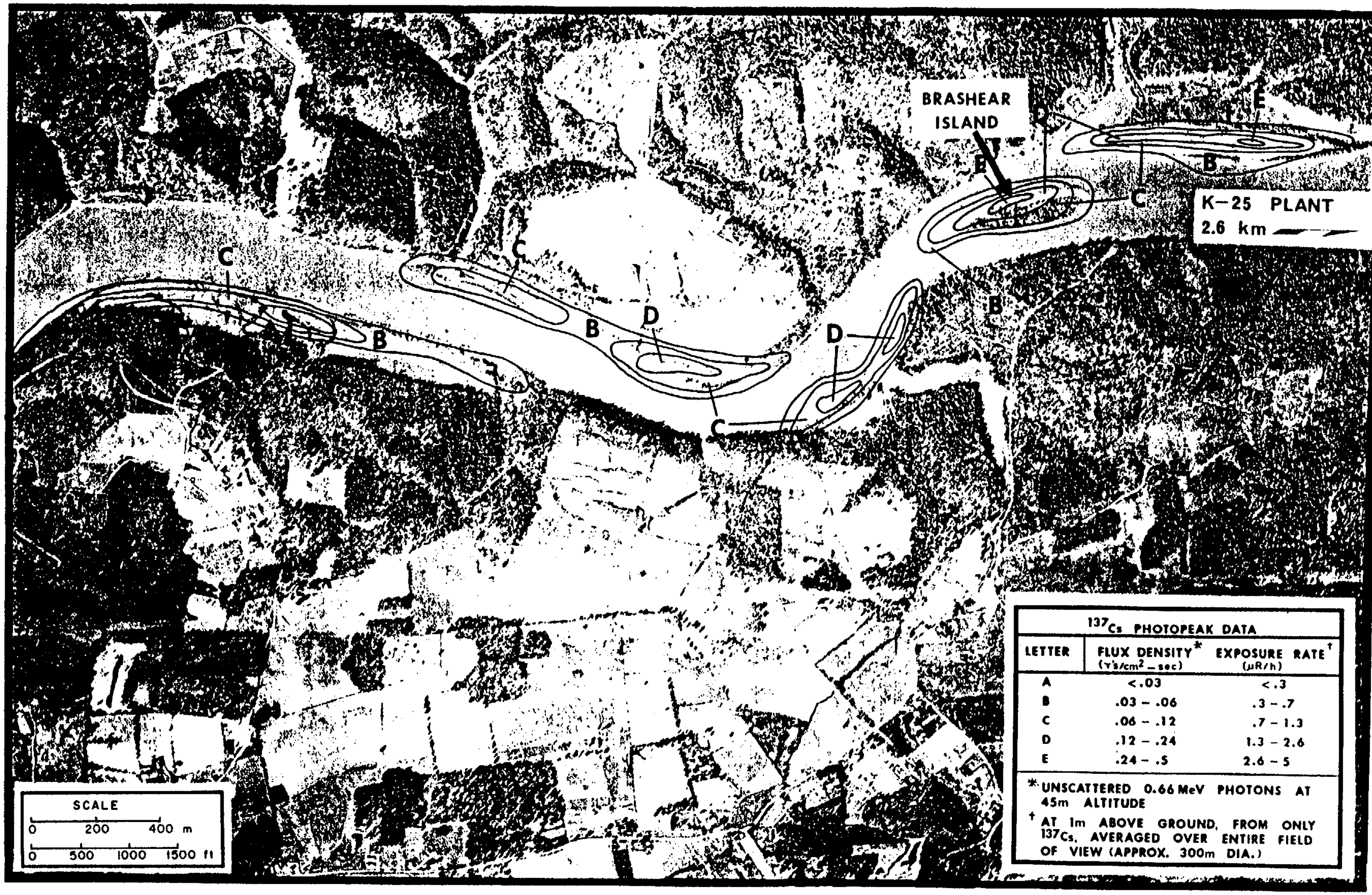


Figure 13. Radiation levels resulting from only ^{137}Cs, inferred from helicopter survey data taken at 45m altitude, Nov 8, 1974, of the river and islands west of K-25, Oak Ridge. Natural radiation levels vary from 5 to 10 μR/h (includes cosmic radiation).

noted in Fig. 8 and 9 and Section 4.2.6, ^{60}Co and ^{137}Cs activity are apparent in the Melton Valley - White Oak Lake drainage basin. Some activity escapes into the river and over a period of several years has resulted in long term buildup of low level activity on some of the mud banks. The Clinch River Study[4] estimates that 662 curies of ^{137}Cs and 270 curies of ^{60}Co were discharged into the Clinch River between 1948 and 1963.

It is interesting to note the apparent accumulation of contamination near the sanitary water treatment plant in Bear Creek Valley (Area I_1 in Fig. 12). The plant takes water from the river, purifies it, and then discharges the residue into a small stream leading back into the river. This stream is the center of the D level as seen in Fig. 12. Evidently, most contamination in the river is removed during the treatment process and then actually concentrated in the residue put back into the stream. The exposure rate near the creek banks is expected to be 15 to 30 μR/h from the contamination.

The survey included flights over similar mud banks as far down stream as the intersection of the Clinch and Tennessee Rivers. No detectable contamination was observed in the Clinch River banks beyond about 8 km down river from the K-25 plant site.

4.2.2 Oak Ridge Gaseous Diffusion Plant, K-25

An isopleth map of man-made radiation for the K-25 plant site is shown in Fig. 14. Five primary source locations, three H-levels and two G-levels, are centered above locations where cylinders of depleted normal and enriched uranium are stored. Hundreds of cylinders, weighing 10 to 14 tons each are stored at these locations. Lower levels were observed over all of the main diffusion buildings.

The isotope measured, ^{234m}Pa (shown in spectral plots 4 and 5, Appendix C), is indicative of the presence of natural uranium, separated from most of its daughter products. It is identified by a photopeak at 1.0 MeV and another at 0.75 MeV. The ^{234m}Pa isotope is the second daughter (after ^{234}Th) of ^{238}U. Its own daughter is ^{234}U, which has a long half-life (2.47 x 10^5 years). These photopeaks (1.0 and 0.75 MeV) are not normally seen in measurements of uranium or uranium ore in its natural state in equilibrium with its daughter products because of dominance of the radon daughter photopeaks. These daughter products (^{226}Ra and others) are normally removed during the milling process.

Figure 14. Radiation levels resulting from only man-made radiation, inferred from helicopter survey data taken at 45m altitude, Nov 8 and 9, 1974, K-25 area, Oak Ridge. Natural radiation levels vary from 5 to 10 μR/h (includes cosmic radiation).

One source location indicated the presence of ^{137}Cs. The center was over a grassy knoll as indicated by spectral plot location number 6. The spectrum (#6 in Appendix C) clearly shows ^{137}Cs. The resolution of the photopeak (having no major degradation due to scattering) indicated a source on or near the surface of the ground. The isopleths shown in Fig. 14 and also in Fig. 8 indicated a source of apparent, unshielded activity of 100 to 250 mCi. After the survey, ground crews ascertained that most of the activity was in the top 20 cm of soil and located in a small area a few meters in diameter. However, the remainder of the activity was distributed over a larger area and several meters deep. The site was the location of an old pilot plant used for uranium enrichment in the late 1940s. The source of contamination is likely to be the result of fission products present in connection with the plant's activities.

4.2.3 White Wing Scrap Yard

The White Wing Scrap Yard had previously been used as a storage yard of contaminated equipment. Most of the equipment had been removed, leaving only small scrap pieces.

The area (about 3 km east of K-25) was surveyed twice; on November 15, 1974, at 75m altitude and 90m survey line spacings, using the full energy spectrum (.05-3.0 MeV) and again on November 20, 1974 at 45m altitude and 90m survey line spacings, using only low energy (5-300 keV) gamma detection. The survey line numbers were 120 thru 125. A man-made gross count rate isopleth is shown in Fig. 15.

A D-level appeared for man made gross count rate over the scrap yard. A full energy spectrum over this area (#7 in Appendix C) indicates the presence of ^{137}Cs and ^{234m}Pa as the dominant sources. An equivalent unshielded surface activity of ^{137}Cs is estimated to be from 25 to 100 mCi from the size and magnitude of the isopleths (from Fig. 8).

The low energy data were processed to identify low energy isotopes, such as ^{241}Am (60 keV) or ^{235}U (185 keV). The low energy spectrum (#8 in Appendix C, summation of 4 lines) shows photopeaks at about 65, 95, and 185 keV. Even though the statistics are poor, the peaks are reasonably evident. The net spectrum was obtained by subtracting a background taken away from the scrap yard and normalizing this spectrum such that counts in channels 205 thru 300 were set equal to those in the spectrum taken over the scrap yard. The photopeaks are probably from ^{234}Th (63 and 93 keV) and ^{235}U (185 keV).

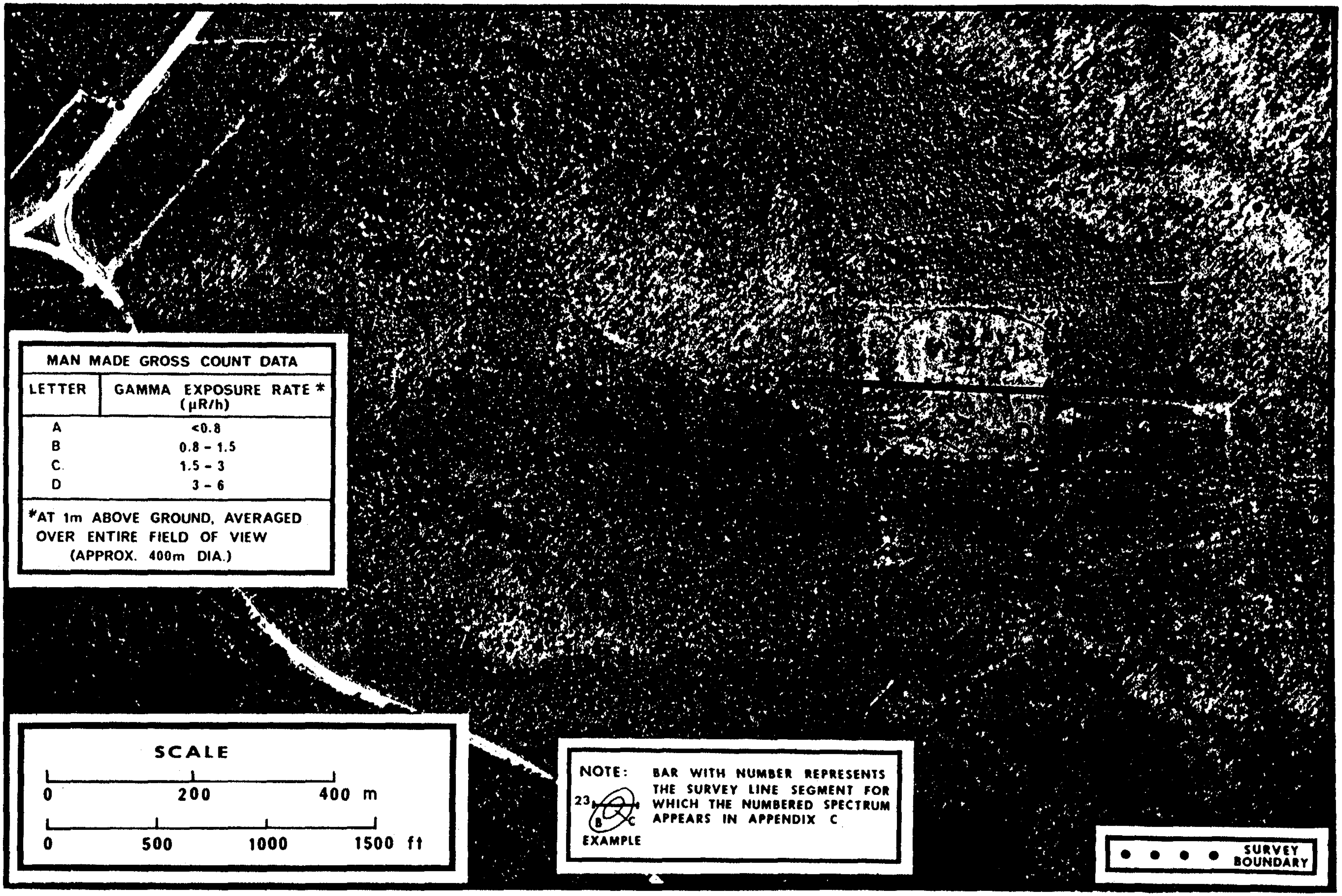


Figure 15. Radiation levels resulting from only man-made radioisotopes, inferred from helicopter survey data taken at 75m altitude, Nov 20, 1974, of the White Wing Scrap Yard, Oak Ridge. Natural radiation levels vary from 5 to 10 uR/h (includes cosmic radiation).

4.2.4 Clinch River Breeder Reactor Site and Vicinity

The entire area between K-25 and X-10 was surveyed twice; once using the full spectrum and once using only the low energy region. This area included the Breeder Reactor site and parts of Chestnut and Pine Ridges. The high energy (0-3 MeV) survey results were processed for ^{60}Co and ^{137}Cs contamination, as well as for any other man-made isotopes. No contamination was detectable at any location except in mud banks in the river as previously mentioned. The low energy (0-300 keV) survey results were processed to search for ^{241}Am and again for any isotope having photopeaks between 50 and 200 keV. Results were all negative. Natural terrestrial radiation levels are shown in Fig. 16. Most of the area indicates low radiation levels (2 to 4 μR/h).

4.2.5 Ecology Study Area on Chestnut Ridge

An ecology study area* on Chestnut Ridge just east of White Wing Road had been contaminated with 4.2 mCi of ^{137}Cs and 37.7 mCi of ^{60}Co 10 to 20 years ago. This area was surveyed on November 9, 1974. A small area reaching a C-level for MMGC is shown in Fig. 17. The spectrum taken over the site clearly shows the presence of ^{60}Co with a small indication of ^{137}Cs (Plot 9 in Appendix C).

From the airborne count rate data and the procedures described in Appendix D, the total apparent surface activity is estimated to be 5 to 10 mCi of ^{60}Co. This value is consistent with the half-life (5.26 years) and the probability of some self shielding provided by the forest.

4.2.6 Oak Ridge National Laboratory (ORNL), White Oak Lake and Vicinity

Many waste storage areas, burial grounds, and radiation experiment areas exist in the vicinity of the X-10 (ORNL) plant and White Oak Lake drainage area. This is particularly evident in the man-made gross count rate isopleth shown in Fig. 18.

A burial ground (ORNL designation #3) is evident west of the laboratory. Spectral plot #10 (Appendix C) reveals the presence of both ^{60}Co and ^{137}Cs as the dominant, gamma-producing isotopes.

*ORNL special identification #14.

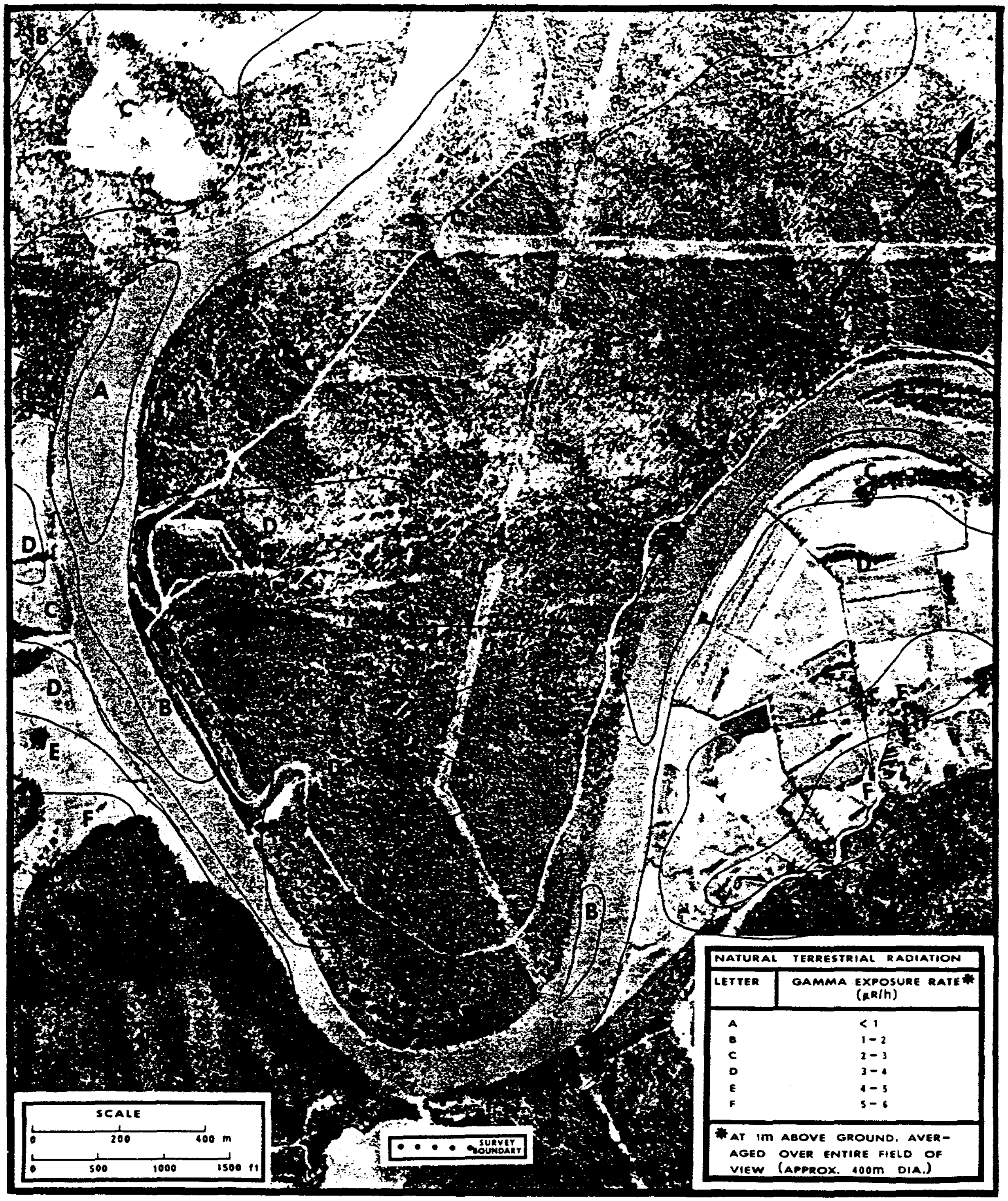


Figure 16. Natural terrestrial radiation exposure rates 1m above the ground inferred from helicopter surveys at 75m altitude of the Oak Ridge Clinch River Breeder Reactor site and vicinity. Survey date Nov 9 and 13, 1974. For total background radiation levels, an exposure rate of 3.8 μR/h should be added to account for cosmic radiation contributions.

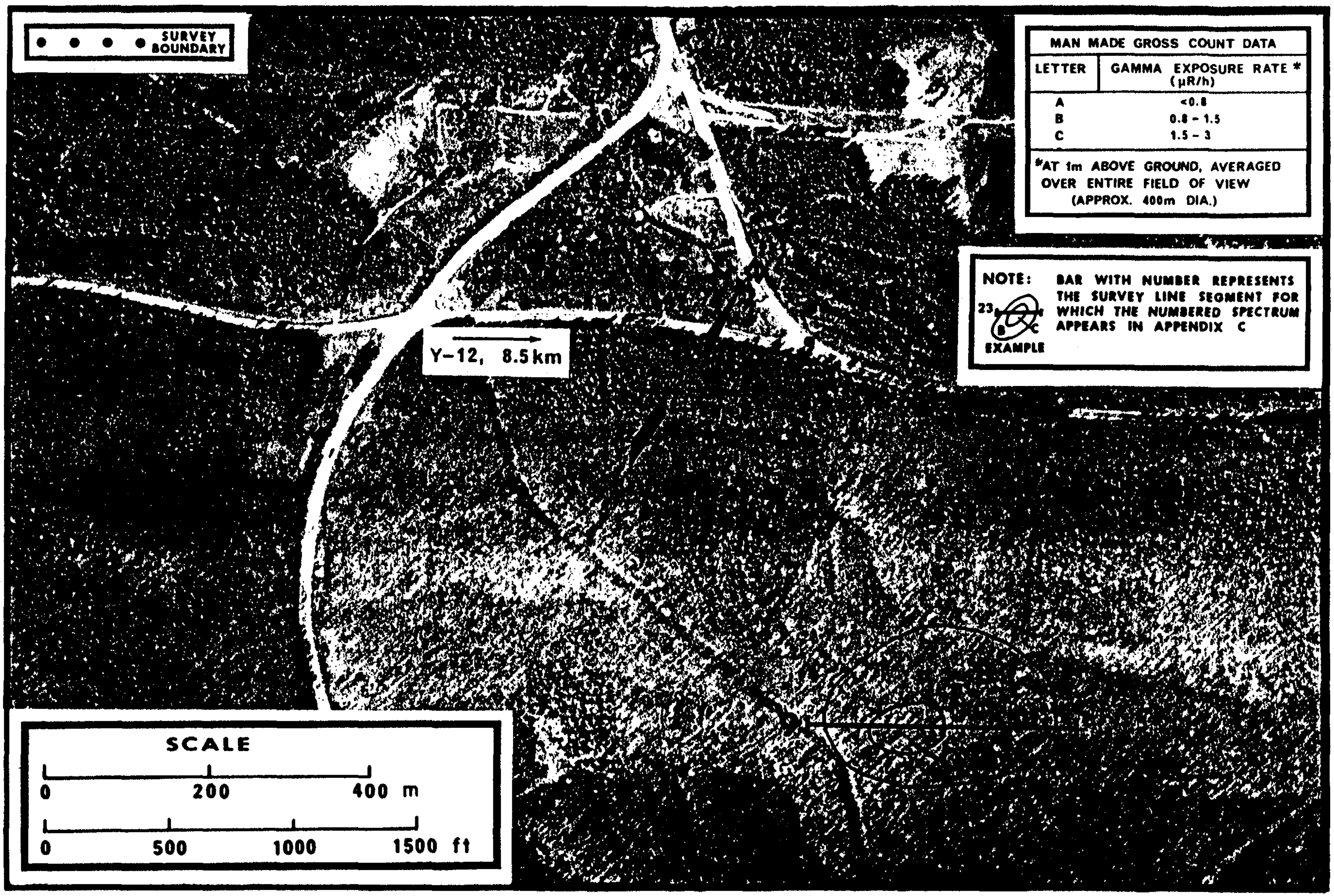


Figure 17. Radiation levels resulting from only man-made radioisotopes, inferred from helicopter survey data taken at 75m altitude, Nov 9, 1974, of an ecology study area (#14), Oak Ridge. Natural radiation levels vary from 5 to 10 μR/h (includes cosmic radiation).

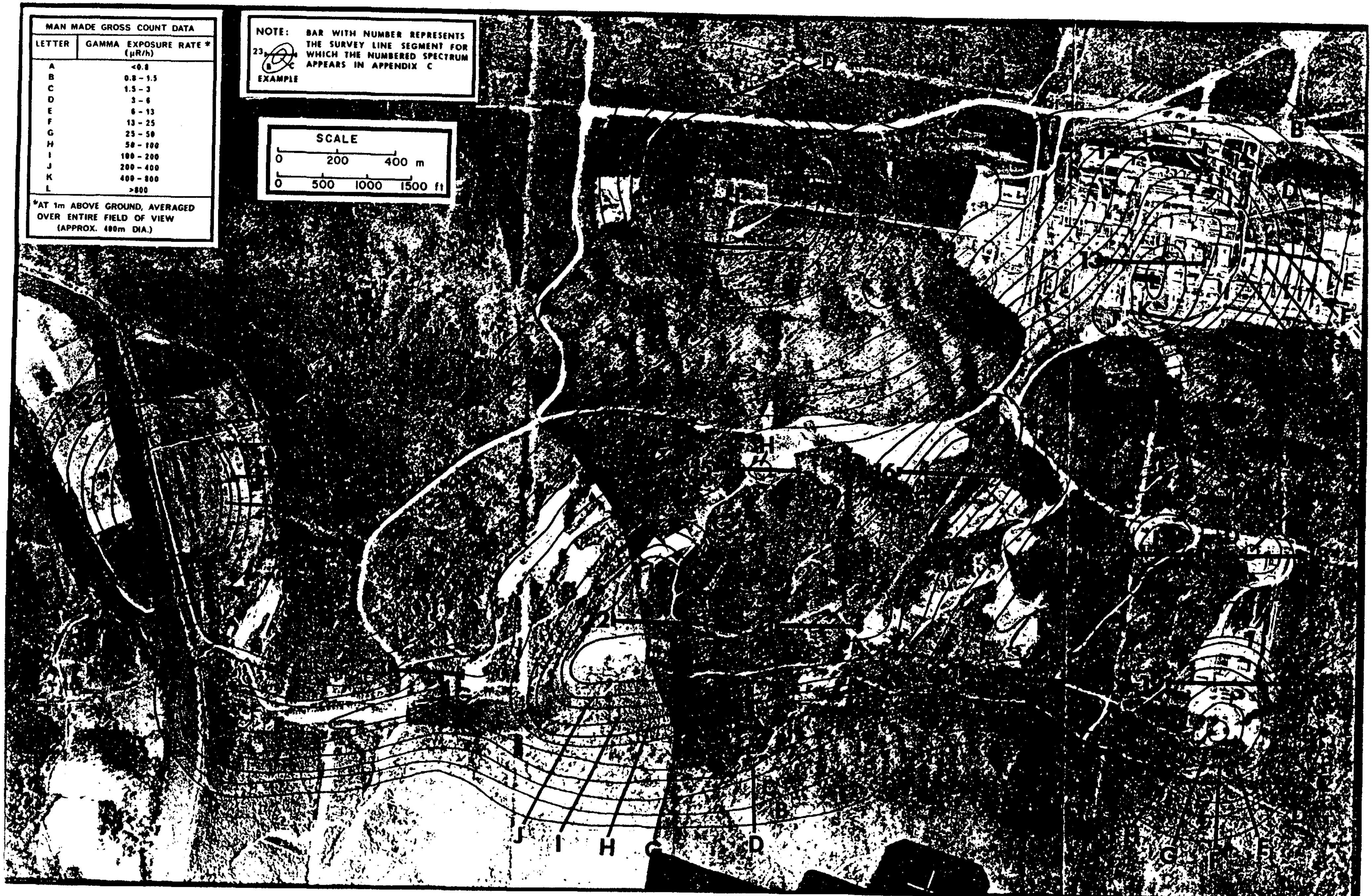


Figure 18. Radiation levels resulting from only man-made radioisotopes, inferred from helicopter survey data taken at 75m altitude, Nov. 12, 13 and 16, 1974, of the X-10 area, Oak Ridge. Natural radiation levels vary from 5 to 10 μR/h (includes cosmic radiation)

A source producing a B level appeared to exist between burial ground #3 and the laboratory. Spectral plot 11 indicates the presence of ^{137}Cs.

The source contributing to the radiation levels over the laboratory appears to be centered at or near the equalization basin for the process waste treatment plant. Spectral plots 12 and 13 reveal the presence of ^{60}Co and ^{137}Cs. Note that spectrum 13 is somewhat distorted due to high count rates, even with only two detectors activated. Spectrum 12 is less distorted. Even though spectrum 12 was taken 375m from where spectrum 13 was taken, both are probably from the same source.

In this regard, it should be noted that the isopleths are derived from data taken 75m above the ground. The B levels extend hundreds of meters in diameter, and in most cases do not reflect sources directly below them but are the result of more intense sources, highly localized, existing in the center or near the focal point of the isopleths.

Spectrum 14 indicates the presence of ^{137}Cs just south of the Lagoon Road resulting in an F level in Fig. 18. The location is a contaminated area resulting from a radiation waste disposal (hydrofracturing) experiment.

An inactive intermediate level waste trench located just west of burial ground #4 indicated an H level primarily from ^{137}Cs (spectrum 15).

A location identified by spectrum 16 produced an L level, on the man-made gross plot in Fig. 18. ^{137}Cs dominated the spectrum. A trace of ^{60}Co was also evident. This location is just below burial ground #4 and is the site of a former intermediate pond.

Gamma radiation, resulting from past activity of a nuclear safety pilot plant (spectrum 17) produced an H level, primarily from ^{137}Cs. Cesium-137 with a trace of ^{60}Co was indicated in the spectrum (#18) taken over the intermediate level waste pumping station.

A source, dominated by ^{60}Co (spectrum 19), appeared to be located at or near the large pond south of the High Flux Isotope Reactor area. An H level was produced on the MMGC plot. The pond is part of a low level waste system (containing activation products). The spectrum (#19) indicated that other isotopes having gamma energies about 0.75, 0.85 and 1.3 MeV may also have been present. The spectrum taken over burial ground #5 (spectrum 20) indicated the presence of both ^{60}Co and ^{137}Cs.

White Oak Lake and drainage basin contained both ^{60}Co and ^{137}Cs as spectral plots 21, 22, and 23 indicate. The elevated radiation levels resulted primarily from routine Oak Ridge National Laboratory discharges in the early years of the atomic energy program. Only a small portion of the radioactivity is contributed by current operations. White Oak Creek and White Oak Lake are within the ERDA controlled area so that the public is excluded from access. The radioactivity remaining in these sediments has provided a source of low level radiation to the equatic environment; the effects of which have been studied for several years by ORNL ecologists.*

Ecology study plots, containing ^{137}Cs (spectrum 24), are located on ERDA property opposite Jones Island. Four separate plots had been contaminated with 2.2 curies each. The plots were $10m^2$ placed in a row with uncontaminated plots in between the contaminated ones. Total distance from the first to the eighth plot was about 260m. As can be seen in Fig. 8 and 18, the isopleths are oblong, indicating more than one source. From the size of the isopleth contours, the apparent surface activity was estimated to be 6 ± 4 Ci.

4.2.7 X-10 - 7000 Area and Vicinity

For convenience, three sites indicating man-made radiation existing east of the main ORNL area are shown separately. The MMGC isopleth for this area is shown in Fig. 19. A G level was reached directly over a warehouse-storage building east of the ORNL - 7000 area. The dominant isotope was observed to be ^{137}Cs (spectrum 25, Appendix C). The source of radiation was three barrels, each separately containing fission products, thorium and radium. The barrels had been stored there temporarily. Small indications of ^{208}Tl and ^{214}Bi are evident in the spectrum. From the shape and magnitude of the isopleth contours in Fig. 8 and 19, the equivalent unshielded activity of the ^{137}Cs source is estimated to be 100 to 300 mCi.

A C level was observed on Chestnut Ridge about 760m north of the 7000 area. An ecology study area (ORNL identification #16) had been contaminated with 4.2 mCi of ^{137}Cs and 37.7 mCi of ^{60}Co 10 to 20 years ago. The study was similar to #14 (described in Section 4.2.5). The spectrum plot (#26) indicates the presence of ^{60}Co and ^{137}Cs. From the photopeak count rate data, the area contains an estimated apparent surface activity of about 5 to 15 mCi of ^{60}Co.

*Personal communications, J. Wing, ERDA-ORO.

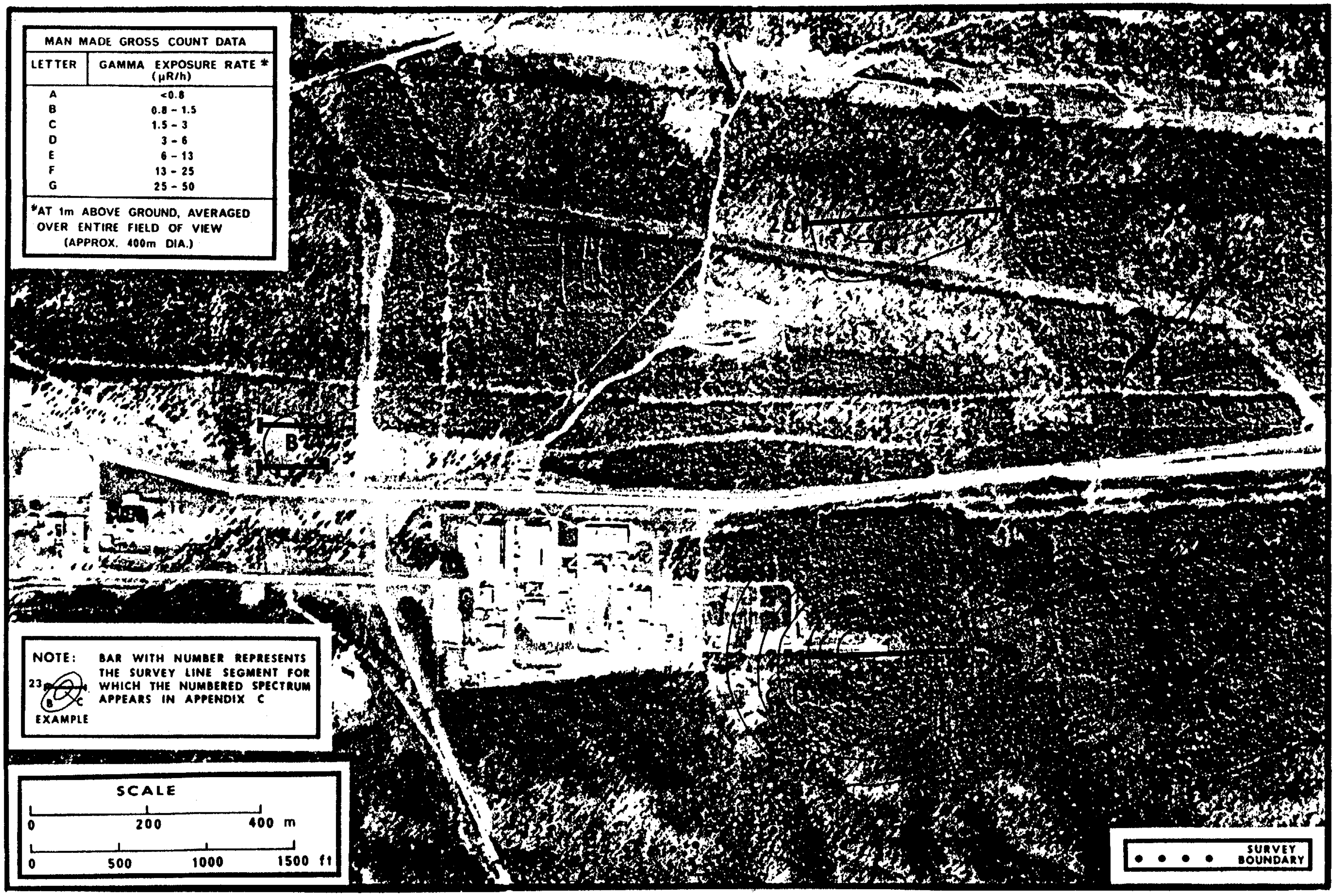


Figure 19. Radiation levels resulting from only man-made radioisotopes, inferred from helicopter survey data taken at 75m altitude, Nov 12, 13, and 16, 1974, of the X-10 7000 area and vicinity, Oak Ridge. Natural radiation levels vary from 5 to 10 μR/h (includes cosmic radiation).

A B level in the MMGC plots was observed on two survey lines passing over the old church and cemetary just north of Bethel Valley Road. Because of gamma counting statistics and the variation in the stripping coefficients, a B level sometimes occurs over natural radiation, giving a false indication of man-made radiation. When a B level occurs side-by-side on two lines, the probability of man-made radiation existing below is increased. A spectrum was extracted from the record on each line showing a B level. After subtracting a normal background, the net spectrum is shown in #27 in Appendix C. There are no photopeaks clearly evident although a hint of ^{137}Cs is indicated. A surface survey failed to locate any source.

4.2.8 HPRR Site and Vicinity

The Health Physics Research Reactor (HPRR) site and vicinity was surveyed on November 16, 1974, at an altitude of 75m with 90m survey line spacing. A radiation intensity isopleth map derived from man-made gross count rates is shown in Fig. 20. A B level was reached over the reactor building. The reactor had not been operated the previous day and only at low levels before that. Furthermore, it was lowered into its shield at the time of the survey.

An F level was observed directly over an ecology irradiation area. Examination of the spectrum (#28 in Appendix C) clearly revealed a ^{137}Cs source below. About 500 mCi of ^{137}Cs had been injected into some trees in May 1962 (ORNL ecology plot #2). The total activity present at the time of the survey then would have been about 375 mCi. From the shape and magnitude of the isopleth contours in Fig. 8 and 20, an equivalent unshielded source activity of 125 ± 50 mCi was indicated from aerial survey data. Considering the probable shielding provided by the trees themselves and the soil covering the roots the agreement is very good.

4.2.9 East Fork Poplar Creek

East Fork Poplar Creek, from Y-12 to K-25, was surveyed at 45m altitude (150m through town) on November 7, 1974. The data were processed for man-made gross count rates. A few B levels appeared just north of Y-12. However, examination of the spectrum did not reveal the presence of any particular isotope (spectrum 29, Appendix C). A C level appeared just south of the Oak Ridge Turnpike

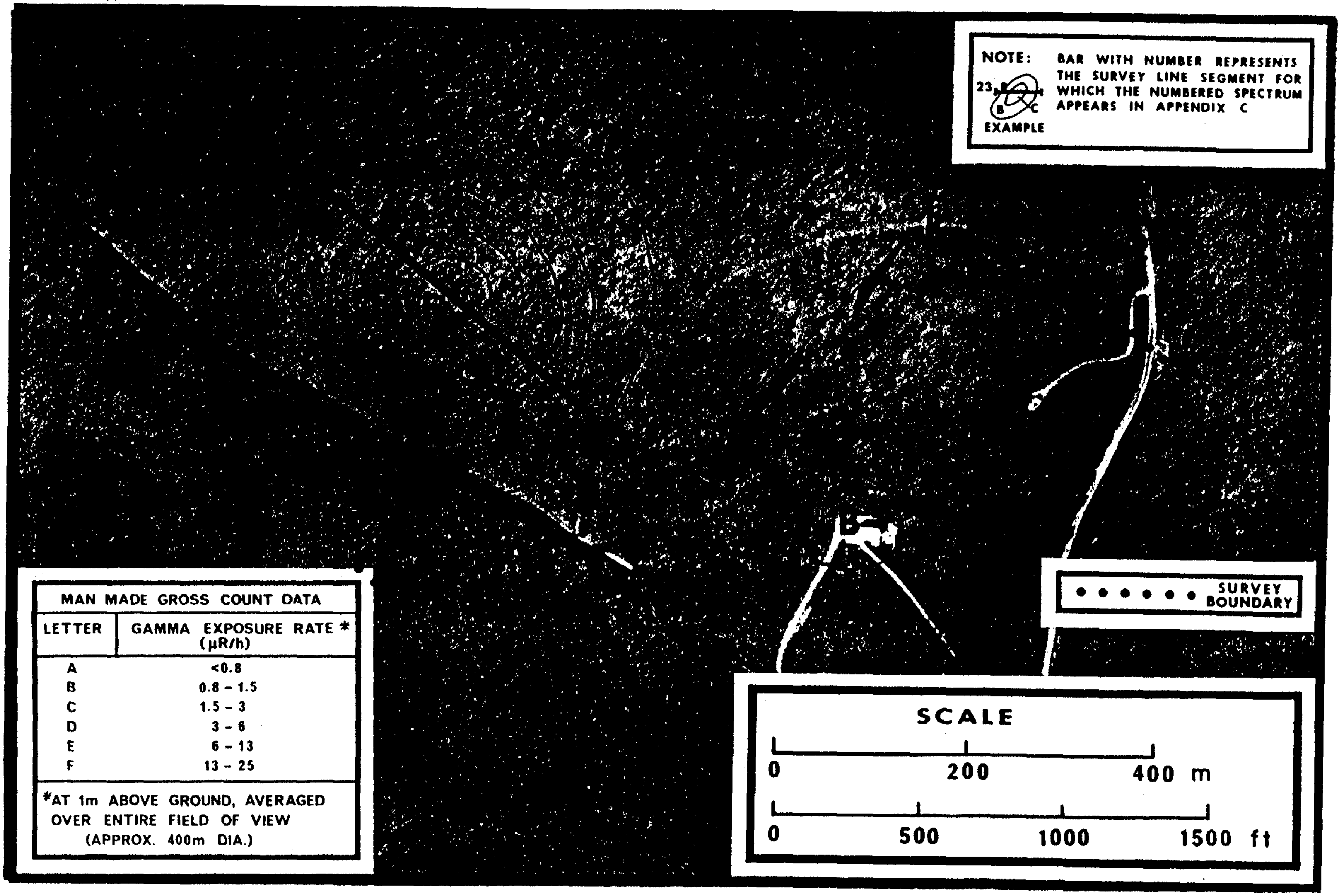


Figure 20. Radiation levels resulting from only man-made radioisotopes, inferred from helicopter survey data taken at 75m altitude, Nov 16, 1974, of the HPRR site and vicinity, Oak Ridge. Natural radiation levels vary from 5 to 10 μR/h (includes cosmic radiation).

about 1.6 km (1 mile) west of Highway 62 (Fig. 21). The spectrum indicated the presence of ^{137}Cs and ^{208}Tl (spectral plot 30). Ground sampling confirmed the existence of elevated concentrations of ^{137}Cs and thorium in the same location. As noted in Fig. 5, the natural radiation levels in the same area were 10 to 15 μR/h. Average radiation levels from ^{137}Cs were about 1 μR/h. The elevated thorium (^{208}Tl) concentrations were probably the result of long-term low-level discharges from the Y-12 plant. The ^{137}Cs contamination was most likely due to long-term buildup of worldwide fallout. The Oak Ridge water treatment plant takes water from the Clinch River (upstream from White Oak Creek) at the rate of 20 million gallons per day, purifies it, and then discharges the residue into East Fork Poplar Creek. Most of the worldwide fallout particulates are removed during the treatment process and then actually concentrated in the residue put into the creek. The same process occurred at the sanitary water treatment plant for K-25 (Section 4.2.1) where only 5 million gallons per day are used.

4.2.10 Y-12 Burial Ground

For convenience of data presentation, the Y-12 burial ground location is shown separately (Fig. 22). The dominant isotope present was ^{234m}Pa with a small indication of ^{208}Tl (spectrum #31, Appendix C).

4.2.11 Y-12 Site and Vicinity

The helicopter survey data taken over the Y-12 plant and vicinity were processed for ^{208}Tl photopeak content since thorium is used at this site in fabrication of special material. A ^{208}Tl photopeak isopleth map is shown in Fig. 23. The A, B, and C categories are not shown since these levels were considered normal background levels and the counting statistics were not sufficient for good spatial resolution. The source at the left of Fig. 23 appears to be centered at the waste disposal pond. This pond contains waste from all the Y-12 facilities. The highest ^{208}Tl count rates (letter I) appeared over the coal pile for the power plant. Actually, there were three or more thorium sources contributing to these isopleths making it appear as if the source was the coal pile. Thorium was stored in the warehouse immediately south of the coal pile. Located immediately north of the pile were old cooling tower basins being used as storage pads. Other thorium sources in the vicinity as indicated in Fig. 23 were located in buildings used for special fabrication. Spectrum 32 (Appendix C) identifies ^{208}Tl.

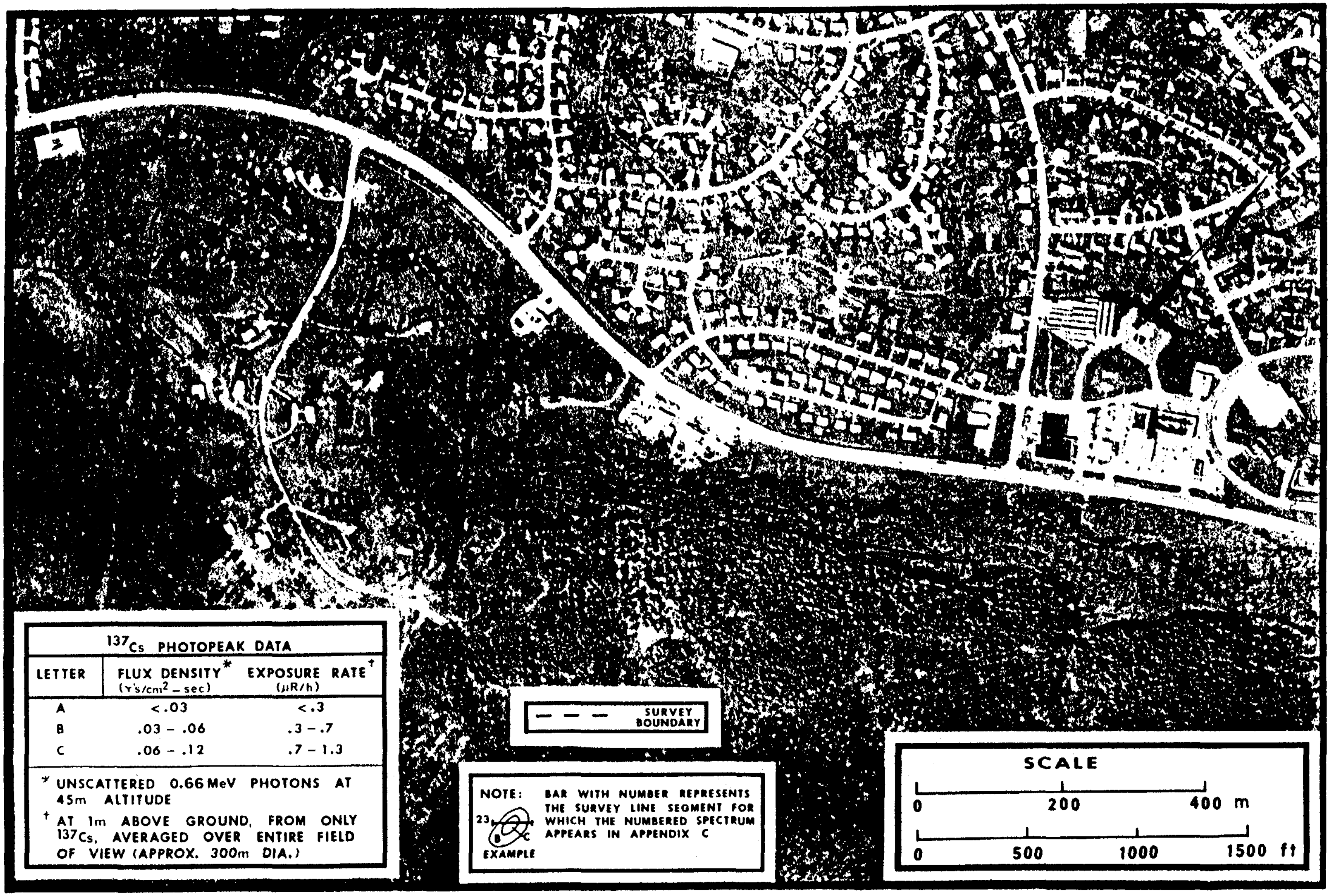


Figure 21. Radiation levels resulting from only ^{137}Cs, inferred from helicopter survey data taken at 45m altitude, Nov 7, 1974, of the East Fork Poplar Creek, Oak Ridge. Natural radiation levels vary from 10 to 15 $\mu R/h$ (includes cosmic radiation).

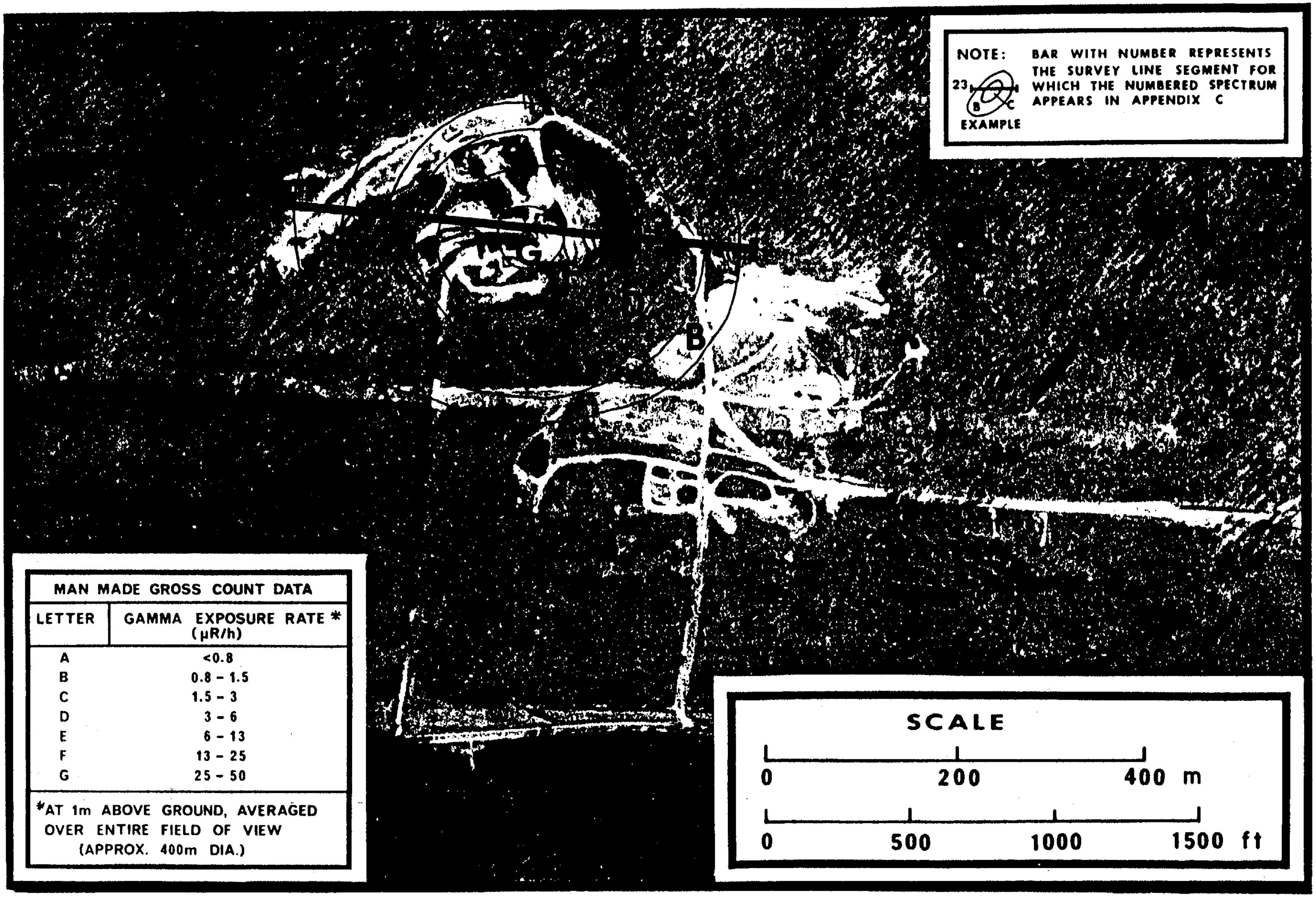


Figure 22. Radiation levels resulting from only man-made radioisotopes, inferred from helicopter survey data taken at 75m altitude, Nov 15, 1974, of the Y-12 burial ground, Oak Ridge. Natural radiation levels vary from 5 to 10 μR/h (includes cosmic radiation).

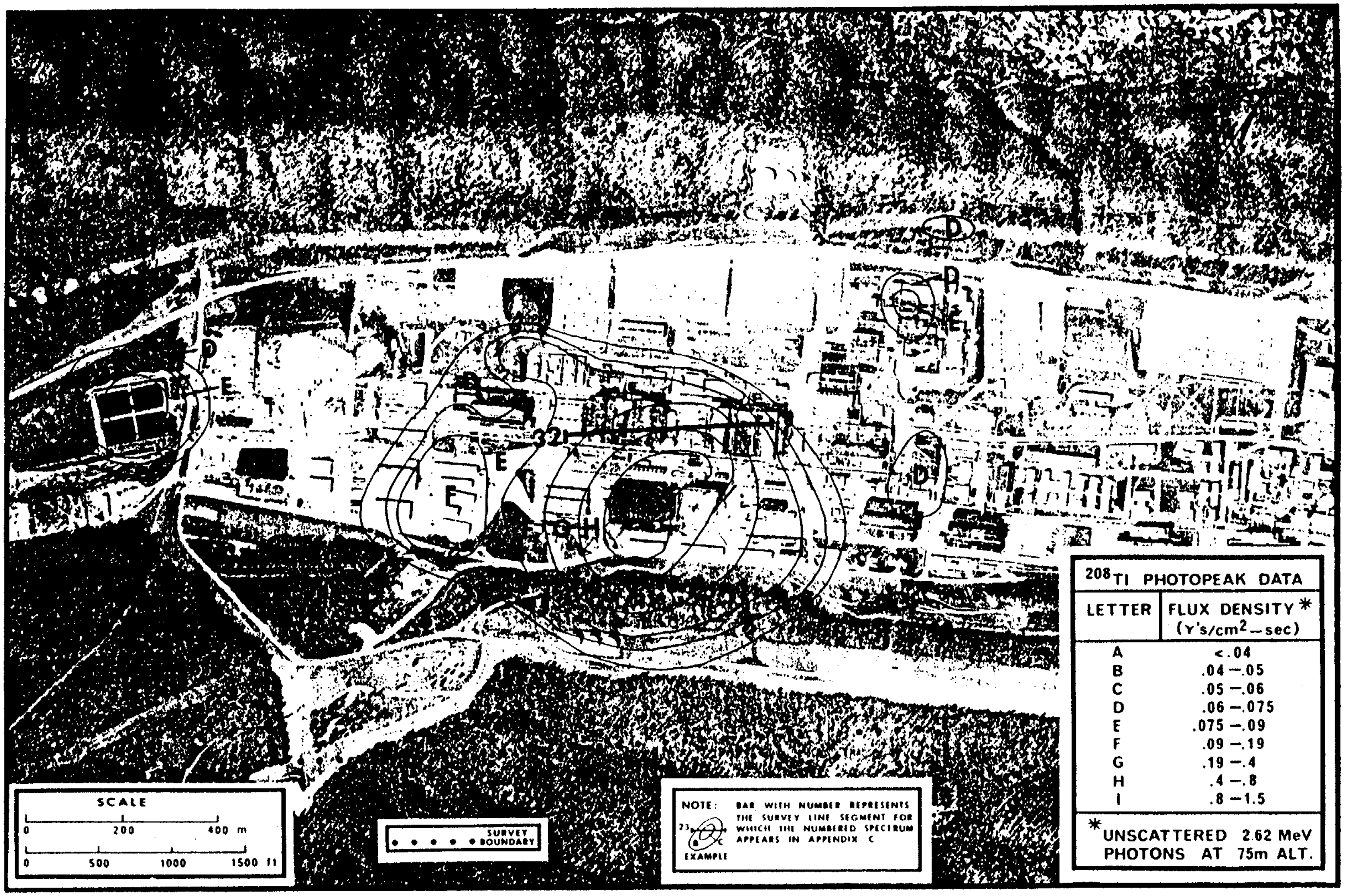


Figure 23. Radiation levels resulting from only ^{208}Tl, inferred from helicopter survey data taken at 75m altitude, Nov 15, 1974, of the Y-12 site and vicinity, Oak Ridge.

A small D level appeared north of the main Y-12 plant (Fig. 23). This was probably due to a higher than average thorium content in the soil at this location.

A radiation intensity isopleth map derived from man-made gross count rates is shown in Fig. 24. A "half" source appears at the far right of the picture. The southern portion of Y-12 was surveyed in the morning of November 15, 1974, and the rest in the afternoon. A source was in use at the Biology building in the afternoon, but not in the morning. Spectral plot 33 identifies ^{137}Cs. The isopleth contours seem to focus on a location to the left of the Biology building. Some shielding near the source may have caused this apparent distortion.

Another ^{137}Cs source (spectral plot 34) appears near some more buildings in the same vicinity. Note the close spacing of the isopleth lines giving the indication of a collimated source. The source was located in a tall building next to a high embankment. This combination produced the collimation effect.

A D level appeared just north of the main Y-12 plant. The spectrum (#35) indicates an abundance of photons below 500 keV. As previously stated, a little higher than normal thorium content existed in the soil near this location. However, it is doubtful if this would have produced the spectrum as shown in spectral plot 35. A ground survey in the area failed to locate any source. A more likely source of radiation was high energy x-ray machines existing in the building directly south. These could have produced the anomaly if they were operating while survey line 156 was being flown but not operating for survey line 155. Exact time-operating-logs were not maintained for the x-ray machines.

An F level is shown over a complex of buildings, identified by spectral plot 36. The primary source indicated is ^{234m}Pa (from uranium) with smaller contributions from ^{137}Cs. The higher energy "tail" in spectrum 36 might be from a thorium source or possibly from high energy x-rays.

Southeast of the above location an E level was produced by a ^{234m}Pa source (photopeaks in spectrum 37). The small ^{208}Tl contribution is probably from a higher intensity thorium source nearby.

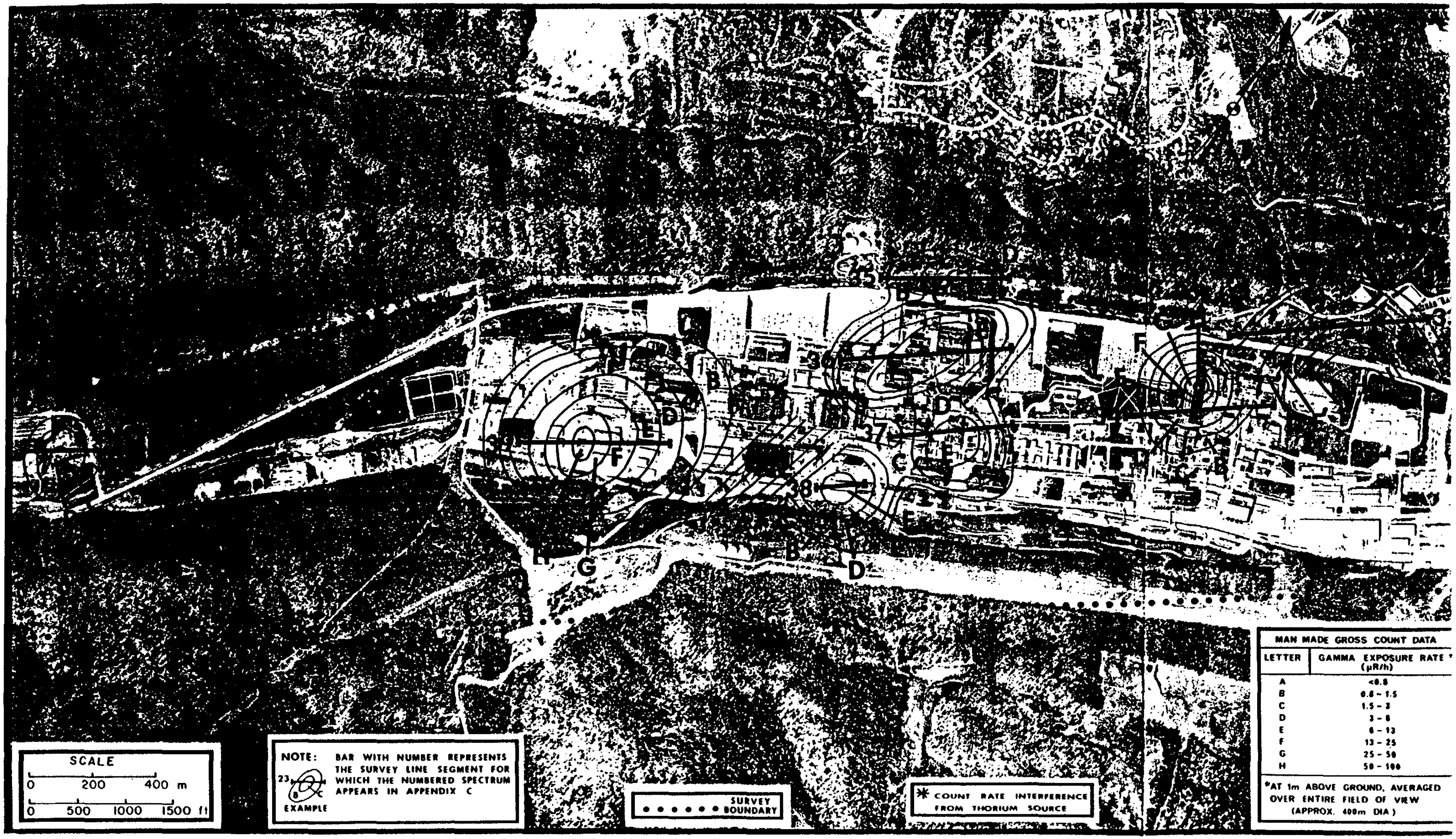


Figure 24. Radiation levels resulting from only man-made radioisotopes, inferred from helicopter survey data taken at 75m altitude, Nov. 15, 1974, of the Y-12 site and vicinity, Oak Ridge. Natural radiation levels vary from 5 to 10 μR/h (includes cosmic radiation).

East of the coal pile (spectral plot 38) an F level was indicated. A warehouse contained large quantities of uranium. A small indication of ^{208}Tl in the spectrum may have been contributed by a thorium source; either in the storage area or nearby.

Tons of ^{238}U were stored near the west end of the Y-12 plant, producing an H level on the isopleths as is indicated in Fig. 24 and spectral plot 39.

An inactive burial ground existed west of the Y-12 plant. It contained uranium as is indicated by the photopeaks of ^{234m}Pa in spectral plot 40.

4.2.12 Bethel Valley and U.T. Farm Area

Bethel Valley, containing the University of Tennessee Comparative Animal Research Laboratory, was surveyed on November 13, 15, and 16, 1974, by helicopter. All of the data were carefully processed according to the procedures given in Appendix D. Other than a small amount of ^{41}Ar present in the air on November 15, 1974, no other man-made radioactive sources were detected.

4.2.13 ERDA Reservation Boundary Survey

On November 21, 1974, a survey was made 90m above the fence line along the north boundary of the ERDA property. The survey began at Chestnut Ridge Park and Melton Hill Lake and followed the north boundary past Y-12, across East Fork Poplar Creek, around K-25, across the Clinch River near Breshear Island and back to the Clinch River at Gallagher Bridge. In processing the data for man-made radiation levels, a B level appeared near the top of East Fork Ridge. The examination of the spectrum, however, did not reveal the presence of any man-made isotopes. A natural radiation "hot spot" appeared at this location, presumably from an outcropping of Chattanooga shale. (see Section 4.1.1)

The southern ERDA boundary was surveyed as a part of the river and island survey on November 7 and 8, 1974. The Watts Bar Lake level was 224.8m and the Melton Hill Lake level was 241.9m above sea level. No significant radiation levels from man-made isotopes were detected other than those mentioned in Section 4.2.1 and Appendix F.

APPENDIX A. INSTRUMENTATION AND DATA SYSTEMS

A.1 Detectors and Data Recording Systems

For the fixed wing survey, September 1973, the primary detector system consisted of three arrays, each containing seven 10-cm diameter by 10-cm thick NaI(Tl) detectors. A secondary system contained an array of seven detectors of the same size shielded on the sides and bottom by about 5 cm of lead. These two systems were mounted inside a Martin-404 fixed wing aircraft.[5] The "dual" detector system had been used as a research tool to separate out the airborne radon daughter gamma ray contribution to the primary detector system.[6]

For the helicopter survey, November 1974, two pods, each containing twenty 12.7-cm dia. by 5-cm thick NaI(Tl) detectors, were mounted externally on a Bell UH-1N helicopter. These individual detectors were shielded on the sides and top with 0.9 mm of cadmium to suppress the low energy scattered radiation, thereby maximizing the sensitivity to ^{241}Am for other surveys.[7] One of these arrays of 20 crystals is shown in Fig. A.1, with the detector pod service cover removed. All detector arrays were thermally insulated and shock-mounted in specially designed packages.

Preamplifier signals from each detector were combined in a summing amplifier in each detector pod. Outputs from the amplifiers were fed to a summing junction in a special data acquisition system called REDAR.* The summing junction output was fed to an analog to digital converter and then to a 305-channel pulse height analyzer and a set of five variable-width single-channel analyzers. A full gamma energy spectrum (up to 3.0 MeV) was acquired and updated every three seconds. Single channel information, scaler flux, was updated every 0.2 second. All these results were stored on magnetic tape. Other parameters, such as altitude, temperature, pressure, and position information, were updated every second and also stored on magnetic tape.

*Radiation and Environmental Data Acquisition and Recording (REDAR).

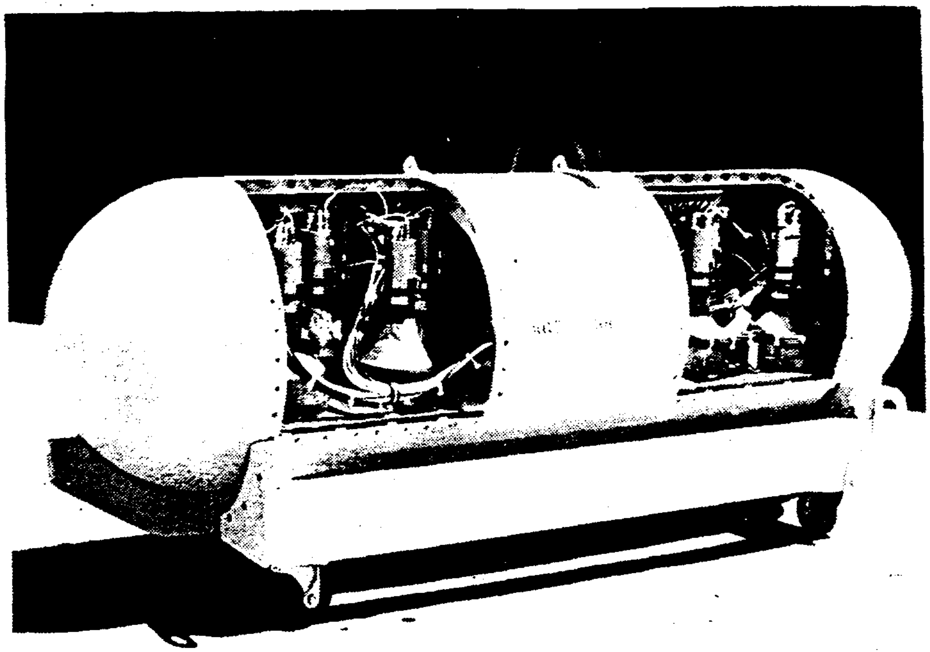


Figure A.1 Gamma detector pod containing twenty 12.7-cm dia., 5-cm thick NaI(Tl) crystals. Two pods were carried external to the UH-1N helicopter for the Oak Ridge Survey.

Real time data observations were made on board the aircraft. Spectral information could be monitored on a CRT display; any one of the single-channel outputs could be monitored on a digital readout; and weighted combinations of the single-channel data could be displayed on strip charts. This allowed for real time observation of the detection of man-made radiation or any isotope of interest.

The data acquisition system (REDAR shown in Fig. A.2, mounted in a helicopter) and its use in ARMS programs have been described elsewhere.[8]

A.2 Position Measuring Systems

Two position measuring systems were used on the Oak Ridge surveys: an inertial navigation system (INS) (used on both surveys) and a microwave ranging system (MRS) (used only on the helicopter survey). The INS (Litton Model LTN-51) determined the aircraft's position in a latitude-longitude grid at any point in time. This information was recorded on magnetic tape each second along the flight line.

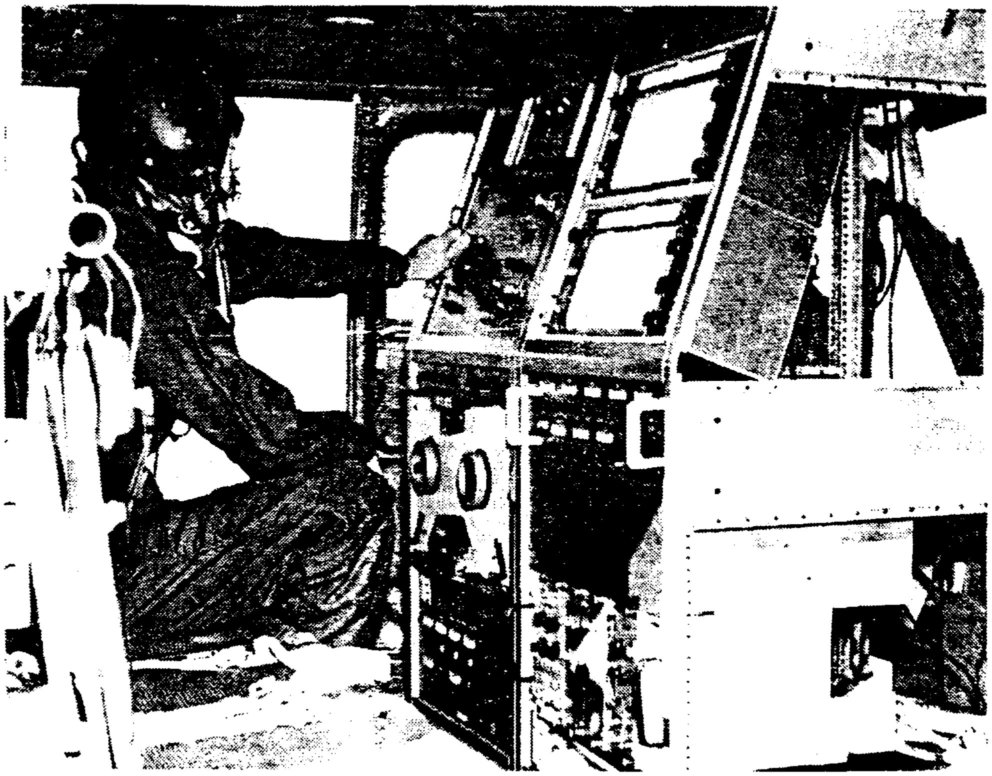


Figure A. 2 Data Acquisition and Recording System mounted in the helicopter.

The MRS utilized a master station, mounted in the helicopter, which interrogated two remote transceivers at fixed locations outside the survey area. By measuring the round-trip propagation time between the master and the remote stations, the master station computed the distance to each. The distance displayed and recorded each second was the average of 10 measurements, which minimized statistical errors and increased system accuracy and stability. The exact position of the helicopter for many of the areas surveyed was determined from information from both INS and MRS units. Details of analysis are described in Appendix D.

A radar altimeter determined the altitude above the ground. Pulses reflected from the nearest ground object were detected by a receiving antenna on the helicopter. The elapsed time was converted to a distance measurement with an accuracy of ± 1.5m, plus 3 percent of actual altitude. This survey was conducted at an altitude of about 75m; hence, the altitude uncertainty from the radar altimeter was about ± 4m.

A. 3 Data Processing System

The data processing system consisted of two magnetic tape transports, a NOVA 840 minicomputer, a CRT display screen with a hard copier, a high speed paper tape reader, and two CalComp plotters. This equipment, shown in Fig. A. 3, was mounted in a mobile van and driven to Oak Ridge for the helicopter survey. *

A large variety of software routines were available for analyzing the data. Pulse height windows could be selected over any portion of the spectrum, in addition to the five single-channel windows, and plotted as a function of time or position on the CRT terminal or on the CalComp plotters. Counting losses due to dead time within the analyzer system and altitude fluctuations could be corrected for. Weighted combinations of windows from either the multichannel or single-channel analyzers could be summed together and the result plotted as a function of time or position. By the proper selection of windows and weighting factors, it was possible to extract the total counts contributed by man-made isotopes or to extract the photopeak count rates from any specific isotope of interest. The resulting gamma count rate information could then be combined with the aircraft position data and plotted on a map, or overlay for a map, along the actual flight lines flown for the survey.

Spectral information, in data blocks representing three seconds of clock time, could be accumulated over any portion of a flight line and plotted on the CRT terminal or the CalComp plotter. Two spectra could be accumulated and stored. Weighted combinations of these two spectra could be formed and plotted. This was valuable in identifying specific photopeaks (corresponding to specific isotopes) along any portion of a survey flight line.

Details on how these software routines were used to analyze and interpret the gamma radiation data are given in Appendix D.

*The data reduction system remained in Las Vegas for the fixed wing survey.

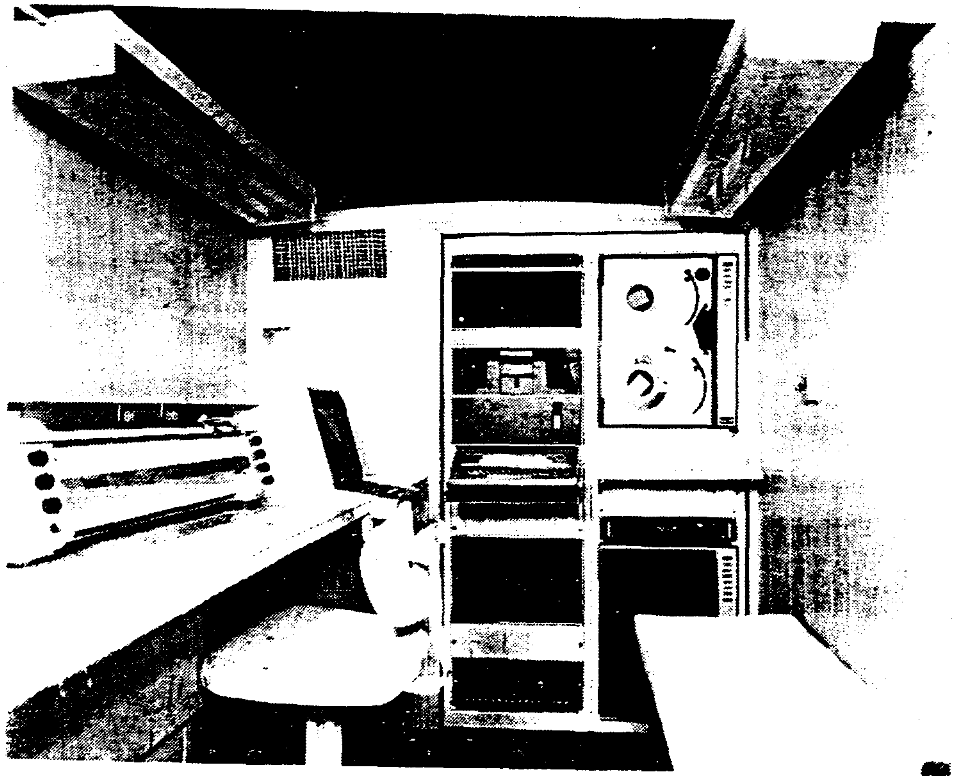


Figure A.3 Interior of mobile van containing the data processing systems used in analysis of the gamma survey data.

APPENDIX B. DESCRIPTION OF THE SURVEY OPERATION

The fixed wing survey was conducted in September 1973. The base of operations was at the Knoxville (McGee Tyson) airport. The flights were made at a nominal altitude of 150m above the ground. A sufficient number of reference points on the ground could be identified on the topographical map, used to navigate by, to keep the aircraft on course. Deviation of 50 to 100m on either side of a survey line was not a serious problem for this type of survey. The reactors at the Tower Shielding Facility and the Health Physics Research Reactor Facility were not operating during flights over these areas. A summary of operational information for the airplane surveys is given in Table B.1.

Table B.1 Operational information for the airplane survey, nominal altitude, 150m.

Date	Time from-to	Survey Lines	Average Air Temperature °C	Average Pressure mm Hg.
9/19/73	13:18-17:01	9-16 41-49	22.7	715
9/20/73	12:10-16:30	4-7 23-28	24.8	717
9/21/73	10:12-13:50	29-40 50-52	25.1	720
9/22/73	11:06-13:04	53-66	26.2	720

Ground based measurements were made at specific locations to support the survey. These are described in Appendix E.

The helicopter survey was conducted in November 1974. The base of operations was at the Air National Guard Station at McGee Tyson Airport. The mobile computer van was also located at the Air National Guard Station to allow checkout of the equipment and partial analysis of the computer tapes during the survey.

A very important part of the helicopter survey was the use of the microwave ranging system (MRS) to determine the exact aircraft position. The two remote MRS units had to be placed at selected locations to meet the following requirements.

1. Direct line-of-site from aircraft to remote unit.

2. Range not to exceed 75 km.

3. Remote units to be oriented such that the angular width for assurance of signal transmission from the remote units to the helicopter should not exceed 90° horizontally nor 5° vertically.

4. Angle separating the lines between the master (aircraft) and the two units to be no less than 30° and no more than 150°.

5. Ease of installation and service (battery life about 3 days).

6. Reasonable assurance of security to prevent theft or damage.

Two primary locations were chosen. One was mounted on a communications tower on top of Buffalo Mountain, a 1000-meter mountain peak located about 13 km northwest of the city of Oak Ridge. The other unit was mounted on a fire tower on Walden Ridge about 5 km northeast of Harriman. These two units did not require any maintenance during the entire survey since power was available at each location. For a small survey near the Oak Ridge Marina, a unit was installed on a TVA tower on Chestnut Ridge near the Clinch River and another on the ground north of the Marina.

Helicopter navigation was done visually with the aid of photographs. Since it was desirable to survey closely spaced lines, maintaining a constant distance between lines, accurate navigation was important. Prior to the survey, aerial photographs were taken of the entire site. A 23 x 23-cm format camera was used, mounted in a special photographic window in a King Air aircraft.[8] The color photographs were blown up to a scale of 70m per cm, cut and taped together for the specific survey areas of interest, and lines drawn on the photographs to correspond to 91-m flight line spacings. The details of the color photos and the color contrasts for that time of year (November) provided the navigator adequate guidelines for good navigation.

Flight line spacings of 91m and a flight altitude of 75m for most of the areas provided a compromise between (1) sensitivity, spatial resolution and total coverage and (2) MRS line-of-sight above the ridges and practical time limitations.

The river and creeks were surveyed first to see if any location needed to be resurveyed in detail. The water level of Watts Bar Lake was low, exposing mud banks and islands not normally seen. Surveys over some of these mud banks revealed the presence of man-made radiation. An island and mud bank survey was then planned and conducted on November 8, 1974, and again on November 16 at an altitude of about 45m. Lines were generally flown on both sides and the center of an island and over parts of mud banks located between Jones Island and the intersection of the Clinch and Tennessee Rivers. For these low altitude surveys, the hills and ridges blocked the line-of-sight between the helicopter and the MRS remote units. A combination of MRS and INS data were used to determine the aircraft position accurately. At the end and beginning of each line, the helicopter would increase altitude until both MRS remote units were observable. At this point a reference signal, called an on-top mark, was placed on the magnetic tape by the navigator. With this method, the INS position data could be used with good accuracy along the line by assuming a constant "INS drift" between MRS reference points.

The combined use of MRS and INS information using the above method allowed accurate position data for many of the other areas as well. The use of the on-top mark, placed on the magnetic tape by the navigator as the aircraft passed over certain identifiable landmarks, was standard procedure for all of the surveys. In this manner, a correlation could be made between the INS position data, given in latitude and longitude coordinates, the MRS position data, given in distance units from each remote station, and certain known reference points along each flight line.

A summary of operational information for the helicopter survey is given in Table B.2.

Table B.2. Operational information for the Oak Ridge helicopter survey.

Date	Time from-to	Area	Survey Line Numbers	Alt. (m)	Temp. (°C)	Press. (mm Hg)	Comments
11/6/74-AM	1320-1500						Initial checkout.
11/7/74-AM	1033-1245	East Fork Poplar Creek, River (N. bank)		45	8.6		
11/7/74-PM	1430-1630	Bear & Grassy		45	11.4		
		Creek, River (S. bank)		45			
		Islands		45			
11/8/74-AM	955-1145	K-25	1-22	75	10.1		
11/8/74-PM	1410-1630	K-25	23-35	75	14.3		
		Islands		45			
11/9/74-PM	1020-1230	K-25	36-46	75	10.8		
		K-25	1A-5A	75			
11/9/74-PM	1415-1617	LMFBR	1, 47-62	75	13.0		
11/12/74-AM	1013-1222	X-10	93-112	75	7.0		
11/12/74-PM	1401-1552	X-10	83-92	75	7.2		
		X-10	89A-91A	75			
11/13/74-AM	1018-1200	X-10 & LMFBR	69-82	75	4.7	750	
11/13/74-PM	1430-1600	X-10 & LMFBR	61A-68	75	9.9	749	
		U.T. Farm	132-139	75			
11/15/74-AM	1007-1233	U.T. Farm	140-142	75	-1.1	761	
		Bull Bluff Rd.	158-163	75			
		Y-12	143-150	75			

Date	Time from-to	Area	Survey Line Numbers	Alt. (m)	Temp. (°C)	Press. (mm Hg)	Comments
11/15/74-PM	1345-1548	Y-12	151-157	75	2.9	761	
		White Wing Scrap	120-125	75			
		Yard	126-131	75			
		McNew Hollow					
11/16/74-AM	1005-1204	X-10	77-105	90	2.6	757	2 detectors
11/16/74-PM	1427-1630	DOSAR	113-119	75	8.4	756	
		Islands	A1-G2	45			
		U.T. Farm	171-174	75			
		Lake Spiral		30-150			
11/20/74-AM	1118-1223	White Wing Scrap Yard	120-125	45	12.5	747	Low energy
		Bear Creek Valley	47, 48	45			Low energy
11/20/74-PM	1410-1638	Bear Creek Valley	48-58	45	13.3	746	Low energy
		LMFBR	60-84	75			Low energy
11/21/74-AM	1028-1235	Am. Nucl. site	164-178	75	5.9	752	
		Boundary		90			
		White Wing Scrap Yard	120A-120B	75			
		DOSAR	113A-113B	75			

APPENDIX C. SPECTRAL DATA

During the airborne radiation survey of the Oak Ridge facilities, a full gamma energy spectrum was taken every three seconds. A 3-second block of data is called a record. Any number of records could be summed for examination.

The spectral data were very useful in identifying the isotopes contributing to the gamma count rates in the detector systems. Identification for all spectra given in this appendix is given in Table C1. The second column contains the figure number in the body of the report identifying the location where the spectrum was taken. The next column generally identifies the area of concern. The column headed "S. C. " indicates a "system configuration" number which was a key word placed on the magnetic tape. The next column indicates the number of records since the beginning of the system configuration. For example, Spectrum No. 2 contains 5 records (14 thru 18) beginning at the 14th record of system configuration #137. The clock time was 15 seconds. The live time was 14. 0 seconds.

A typical spectrum accumulated over a ground location containing only natural radiation is shown in Spectrum No. I. A spectrum taken over an ecology study area is shown in No. II. Note the ^{60}Co and ^{137}Cs photopeaks superimposed on the natural background spectrum. Spectrum III contains the net spectrum resulting from the subtraction of Spectrum No. I from that in II after both had been normalized to the same live time. The net spectrum in No. III clearly reveals the photopeaks identifying ^{60}Co and ^{137}Cs.

The net spectrum was very useful in examination of all source locations. The method of live time normalization was used in most cases. Sometimes it was more revealing to normalize to the number of counts in channels 140 thru 299, thereby forcing the natural background contributions to be zero.

A typical low energy spectrum accumulated over a ground location containing only natural radiation is shown in Spectrum No. I-V. A low energy spectrum over the U. S. Nuclear Fuel Fabrication Plant is shown in No. V. Spectrum V-I shows the net spectrum, revealing the presence of ^{235}U below (photopeak at 185 keV).

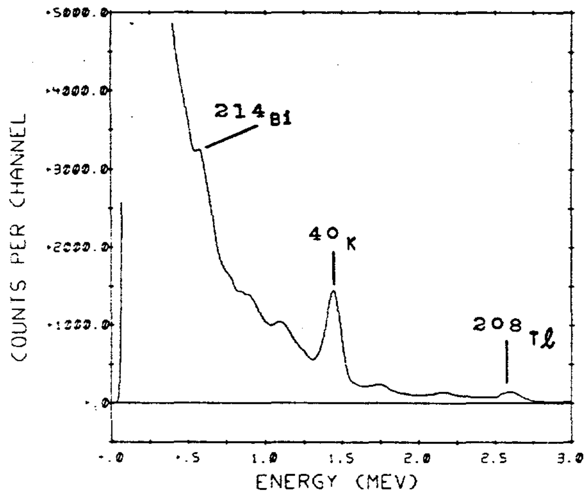
The spectra in the rest of the appendix correspond to those cited in the text.

TABLE C1 Spectral Data

Spectrum No.	Reference Figure No.	Area	Line No.	S. C.	Records	Live Time (sec)	Date	Inferred Isotopes
I		Background	81	407	1-30	84.1	11/13/74	Natural
II		Ecology area	64	462	8-12	14.2	11/13/74	^{60}Co & ^{137}Cs
III		Net over ecology area	64	462	8-12	14.2	11/13/74	^{60}Co & ^{137}Cs
I-V		Background	52A	756	36-39	10.3	11/20/74	Natural
V		Fuel fab. plant	52A	756	52-55	10.0	11/20/74	^{235}U
V-I		Net over fuel fab. plant	52A	756	52-55	10.0	11/20/74	^{235}U
1	15	Island	A-37	162	4-5	5.3	11/8/74	^{137}Cs & ^{60}Co
2	16	Bank west of K-25	26	137	14-18	14.0	11/8/74	^{137}Cs & ^{60}Co
3	16	Water treatment plant	51	262	51-65	41.6	11/9/74	^{137}Cs & ^{60}Co
4	18	K-25	28	141	28-39	28.1	11/8/74	^{234m}Pa
5	18	K-25	16	108	38-45	18.5	11/8/74	^{234m}Pa
6	18	K-25	23	129	17-19	7.7	11/8/74	^{137}Cs
7	19	White wing scrap yard	121-123	559-567	-	49.6	11/15/74	^{137}Cs & ^{234m}Pa
8	19	White wing scrap yard	120-123B	728-731	-	50.0	11/20/74	^{234}Th & ^{235}U
9	21	Ecology study area	64	462	8-12	14.2	11/13/74	^{60}Co & ^{137}Cs
10	22	X-10, burial ground #3	83B	622	2-7	17.7	11/16/74	^{60}Co & ^{137}Cs
11	22	X-10	79	411	72-73	5.6	11/13/74	^{137}Cs
12	22	X-10, laboratory	79	411	76-81	15.8	11/13/74	^{60}Co & ^{137}Cs
13	22	X-10, laboratory	83B	622	17-20	10.0	11/16/74	^{137}Cs
14	22	X-10	91	367	34-35	5.1	11/12/74	^{137}Cs
15	22	X-10, former ILW trench	93B	612	15-17	8.8	11/16/74	^{137}Cs
16	22	X-10, burial ground #4	93B	612	22-25	9.4	11/16/74	^{60}Co & ^{137}Cs
17	22	X-10, pilot plant	96	346	18-21	9.2	11/12/74	^{137}Cs
18	22	X-10, ILW pumping station	96	346	15-17	8.1	11/12/74	^{137}Cs
19	22	X-10, HFIR	101	334	16-19	10.3	11/12/74	^{60}Co
20	22	X-10, burial ground #5	101	334	23-26	9.7	11/12/74	^{60}Co & ^{137}Cs
21	22	X-10, White Oak Lake	99B	604	20-22	7.0	11/16/74	^{60}Co & ^{137}Cs
22	22	X-10, White Oak Lake	99B	604	14-17	8.9	11/16/74	^{60}Co & ^{137}Cs
23	22	X-10, White Oak Lake	101	334	43-45	7.3	11/12/74	^{60}Co & ^{137}Cs
24	22	Ecology study plots	91	367	49-51	7.9	11/12/74	^{137}Cs
25	23	X-10, 7000 area	89A	377	10-12	6.5	11/12/74	^{137}Cs

TABLE C1 Continued

Spectrum No.	Reference Figure No.	Area	Line No.	S. C.	Records	Live Time (sec)	Date	Inferred Isotopes
26	23	Ecology study area	81	407	103-106	11.2	11/13/74	^{60}Co & ^{137}Cs
27	23	X-10 (church & cometary)	83 & 84	387, 389	-	5.6	11/12/74	-
28	24	Ecology area near HPRR	116	672	-	13.3	11/16/74	^{137}Cs
29	11	East Fork Popular Creek - Y-12	-	030	19-28	27.4	11/7/74	-
30	25	East Fork Popular Creek	-	036	50-63	37.4	11/7/74	^{137}Cs
31	26	Y-12 Burial ground	153	547	79-84	14.9	11/15/74	^{234m}Pa
32	27	Y-12	151	543	31-34	9.5	11/15/74	$^{208}T\ell$
33	28	Y-12	153	547	14-22	23.7	11/15/74	^{137}Cs
34	28	Y-12	150	536	63-68	16.4	11/15/74	^{137}Cs
35	28	Y-12	156	553	51-54	10.7	11/15/74	X-rays
36	28	Y-12	153	547	31-37	17.2	11/15/74	^{234m}Pa & ^{137}Cs
37	28	Y-12	150	536	53-59	10.6	11/15/74	^{234m}Pa
38	28	Y-12	148	532	53-54	4.3	11/15/74	^{234m}Pa & $^{208}T\ell$
39	28	Y-12	150	536	43-48	13.4	11/15/74	^{234m}Pa
40	28	Y-12	150	536	28-32	13.6	11/15/74	^{234m}Pa
41	D1	U. S. Nuclear plant	52A	756	52-55	10.0	11/20/74	^{235}U
42	D2	American Nuclear site	168	836	10-18	20.0	11/21/74	^{60}Co



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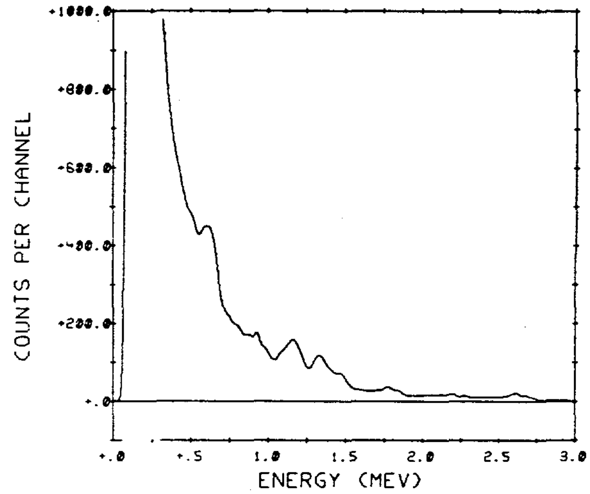

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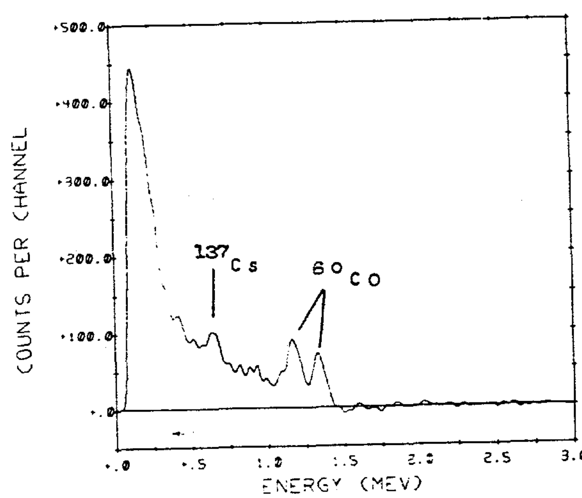

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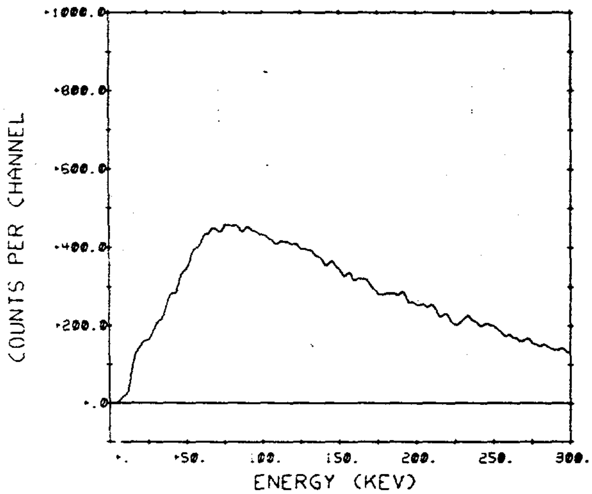

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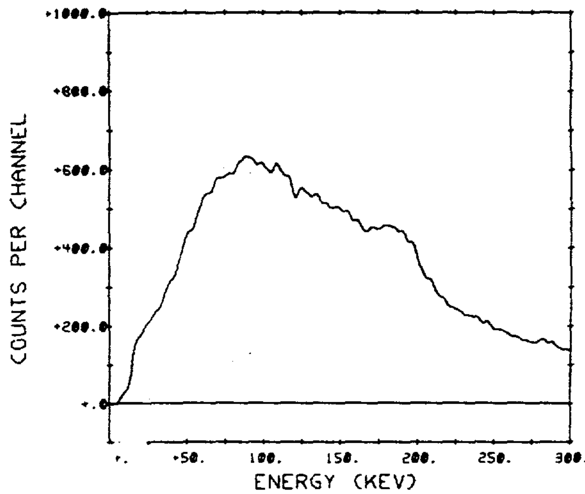

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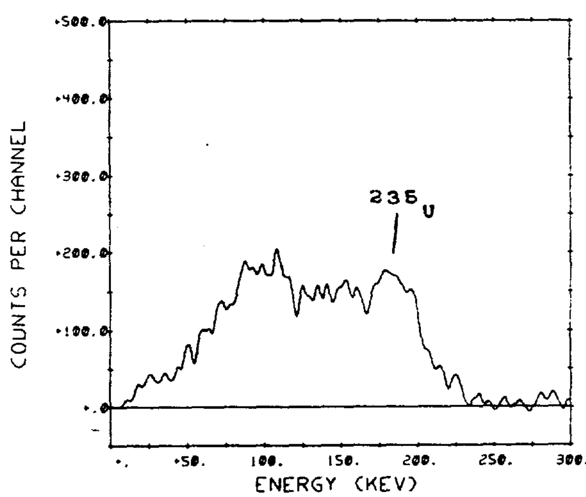

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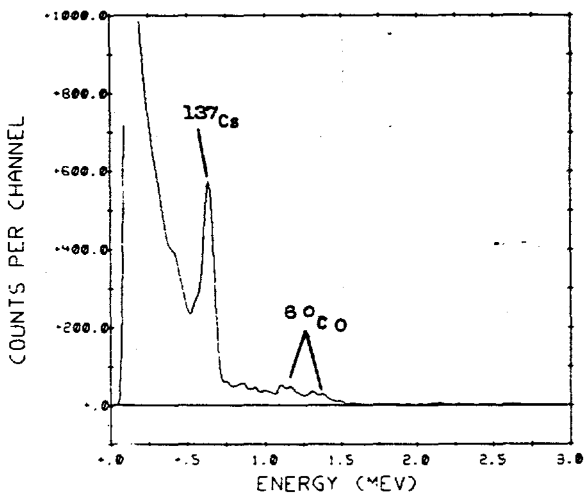

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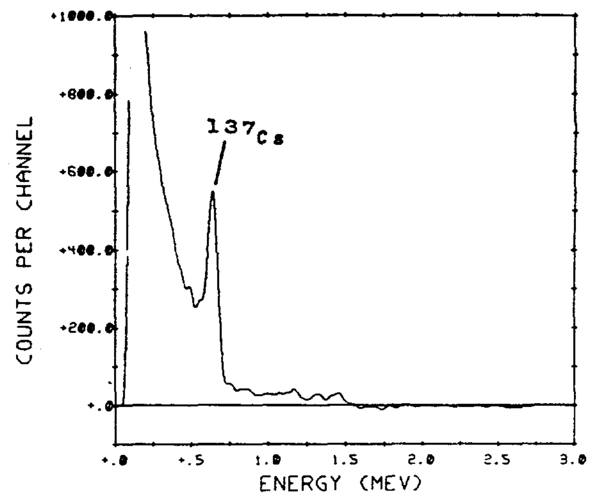

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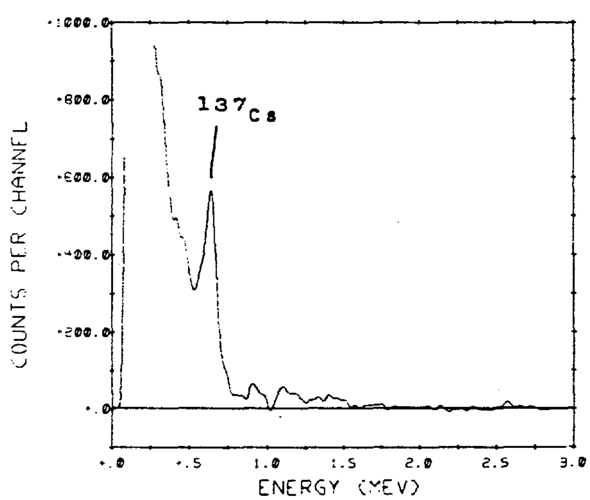

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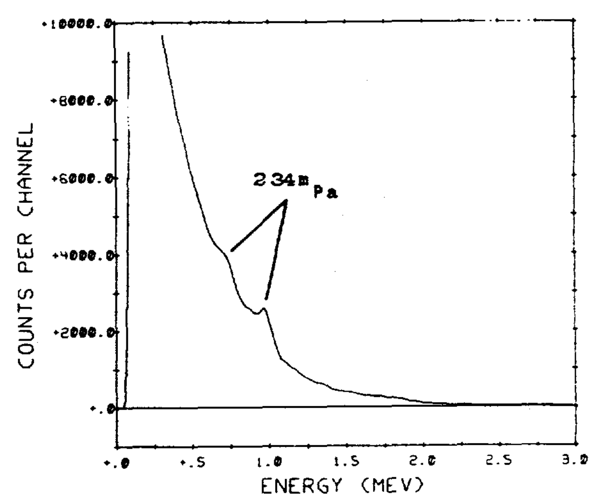

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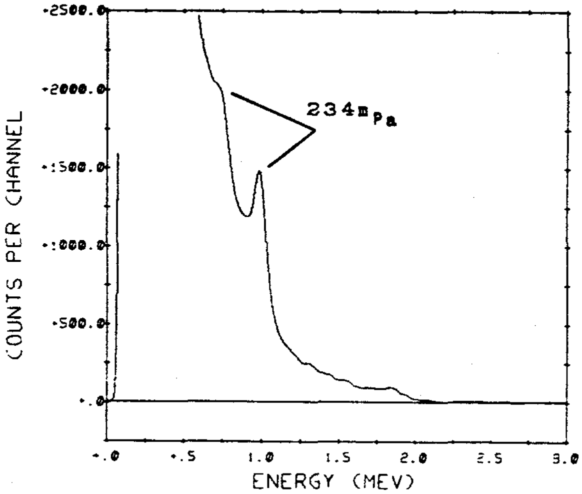

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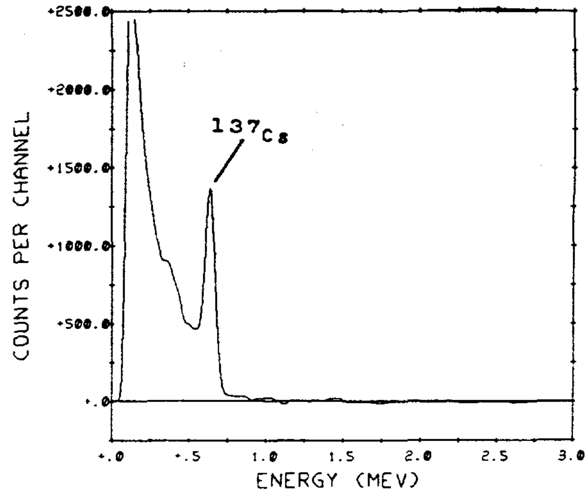

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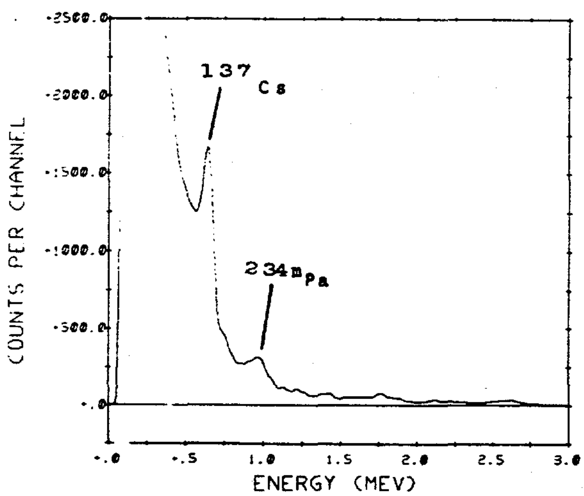

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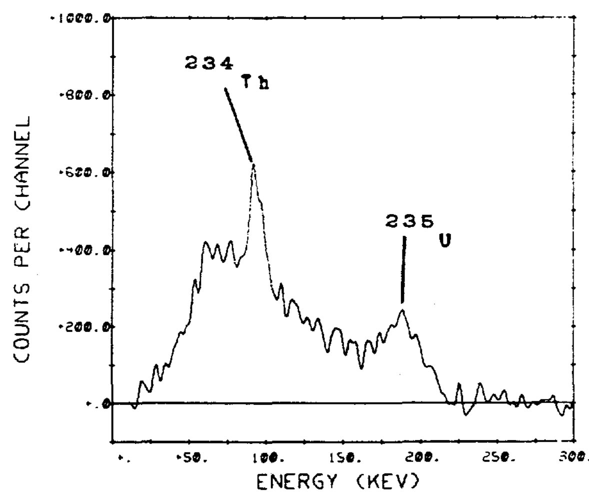

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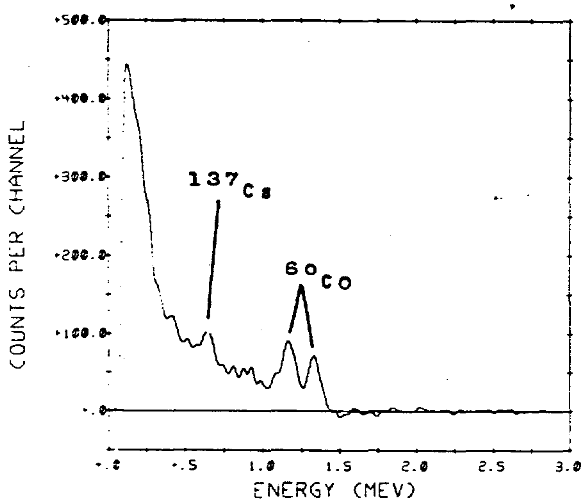

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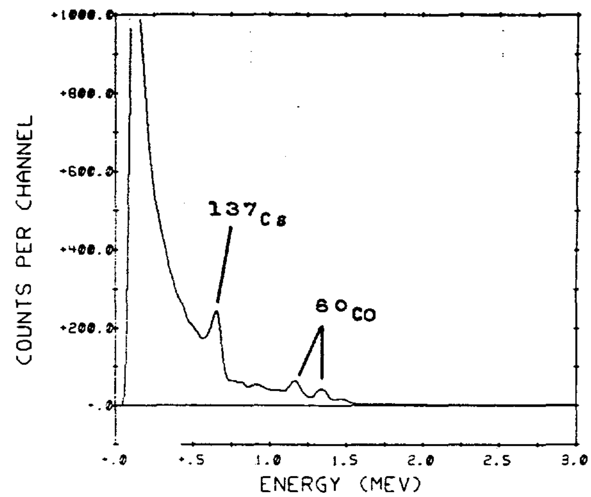

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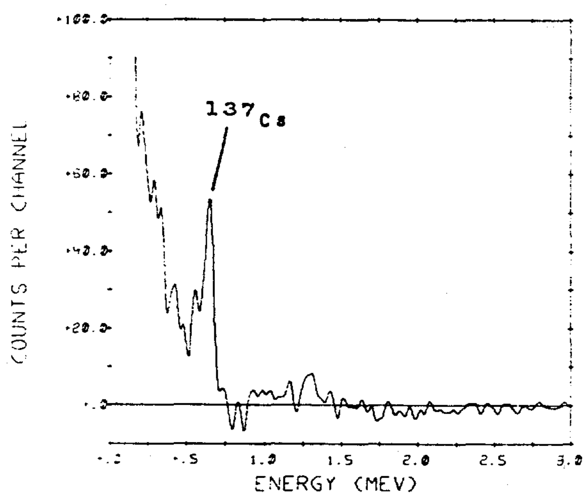

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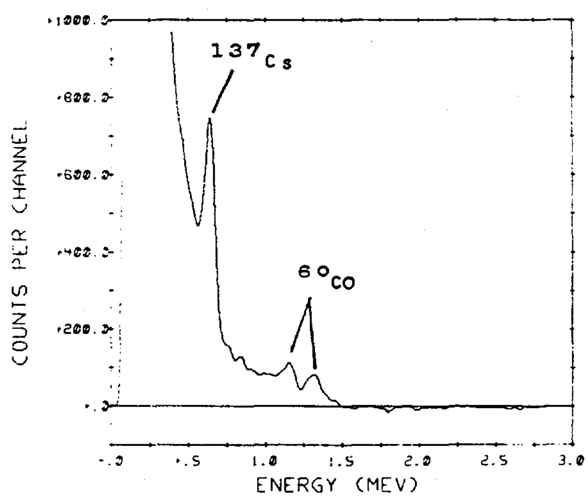

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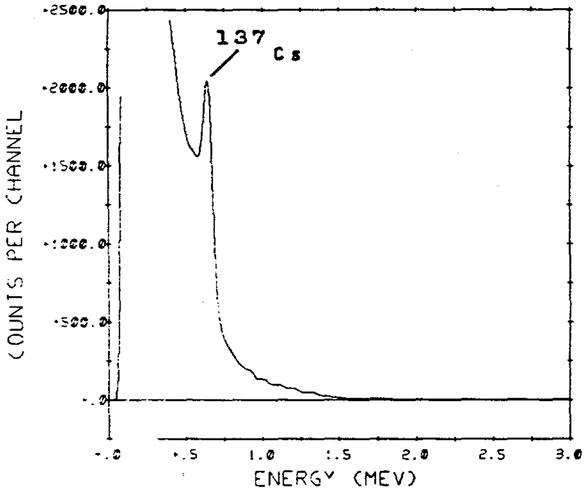

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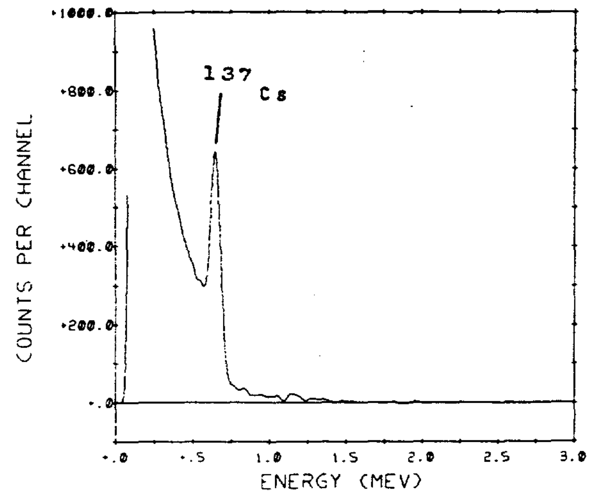

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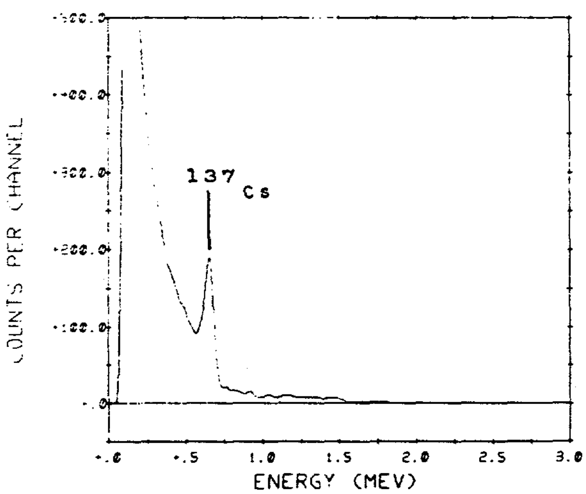

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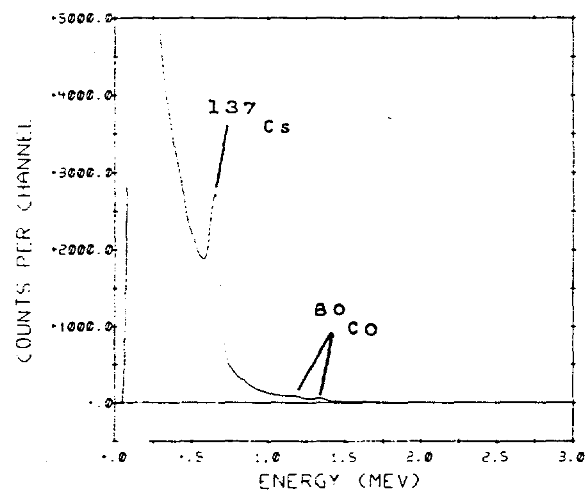

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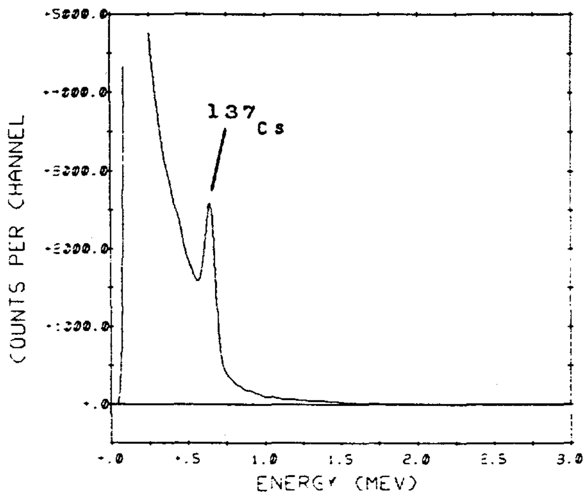

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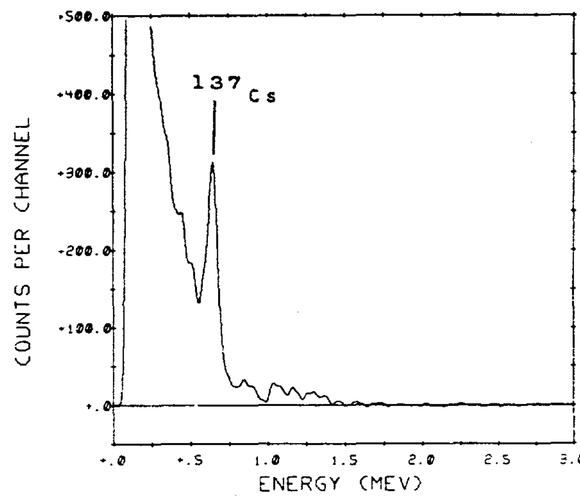

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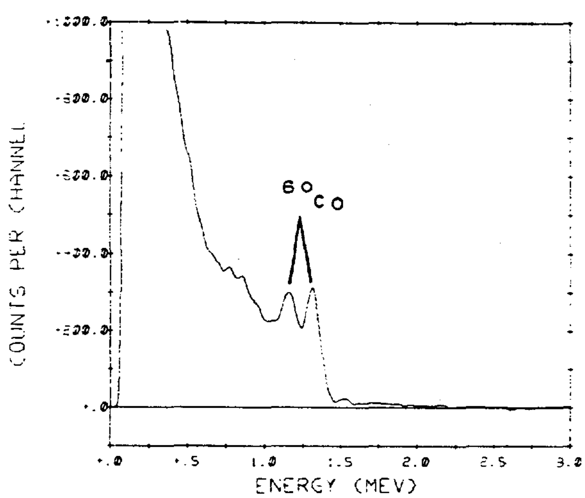

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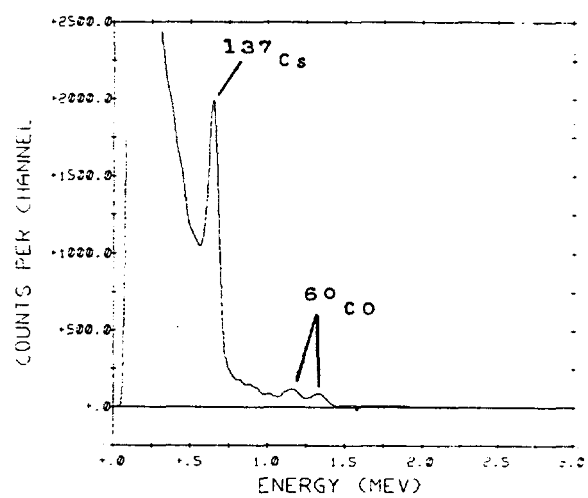

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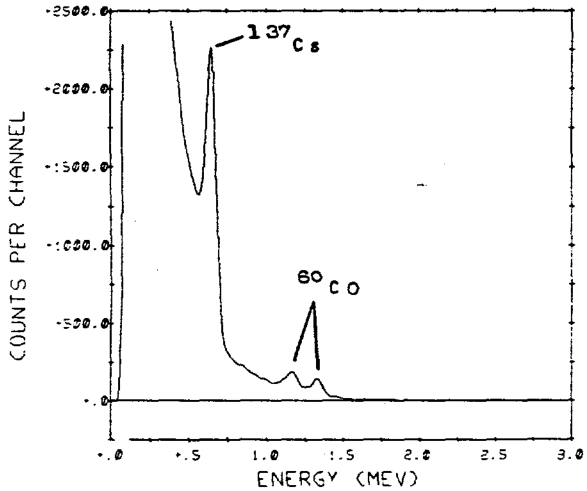

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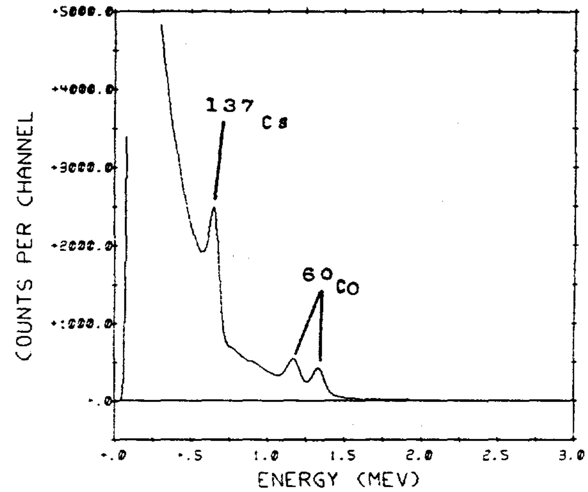

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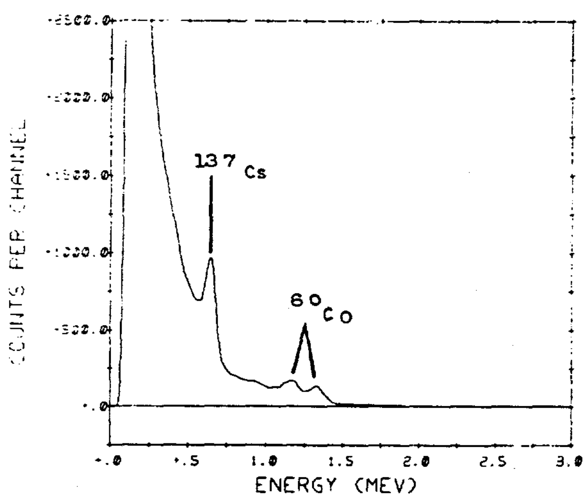

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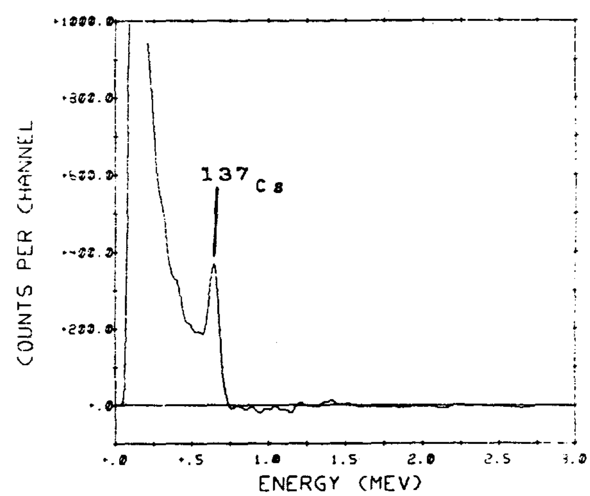

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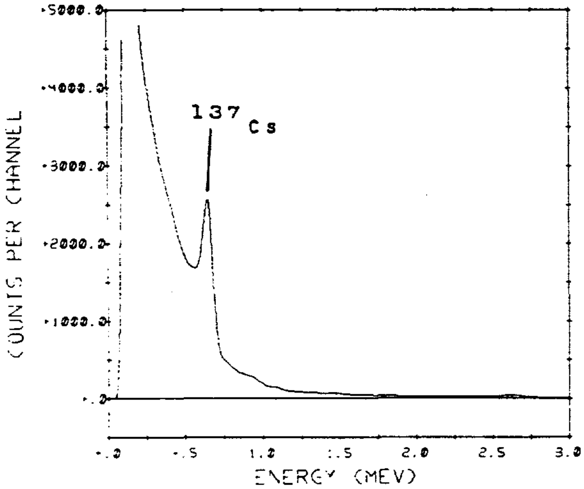

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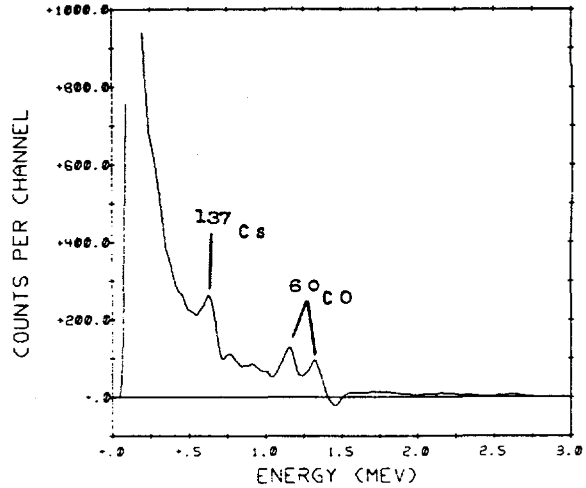

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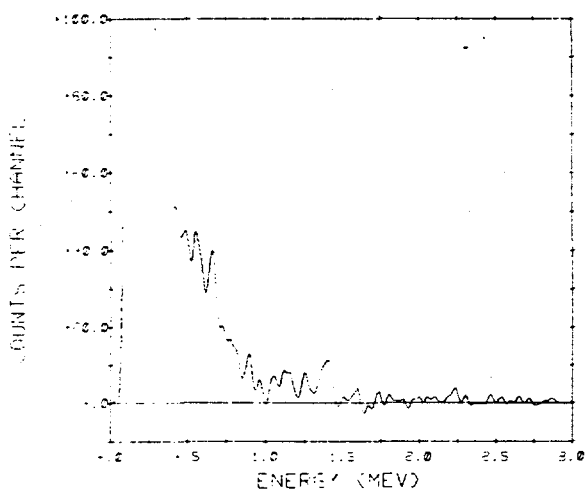

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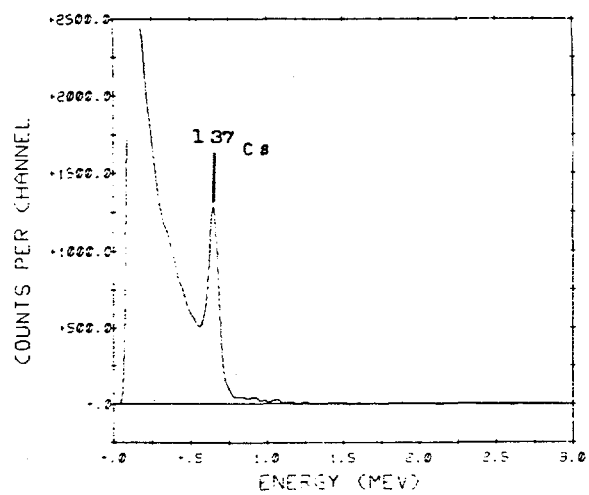

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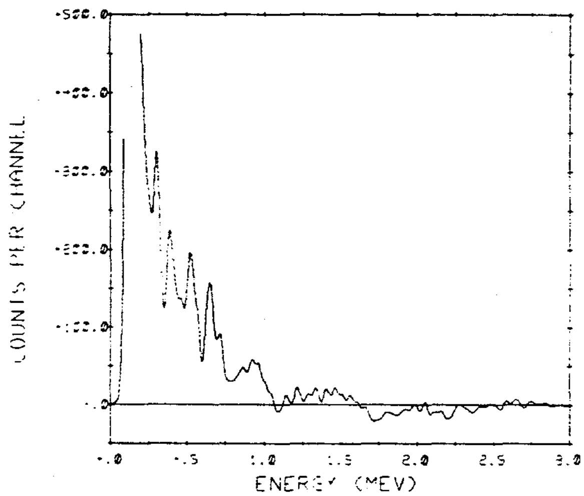

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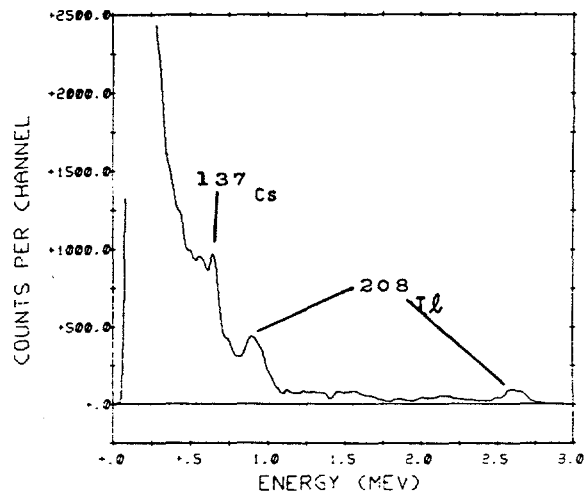

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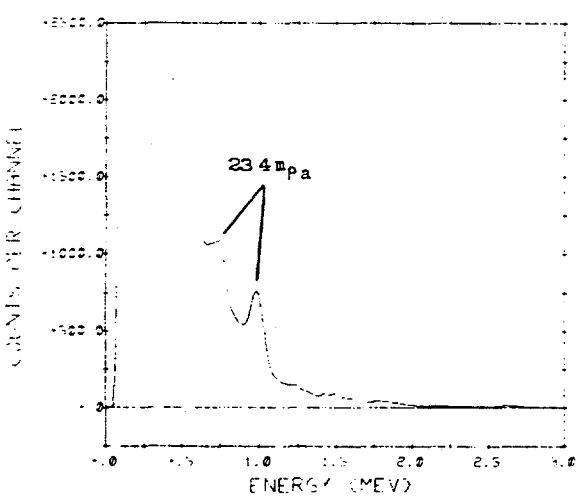

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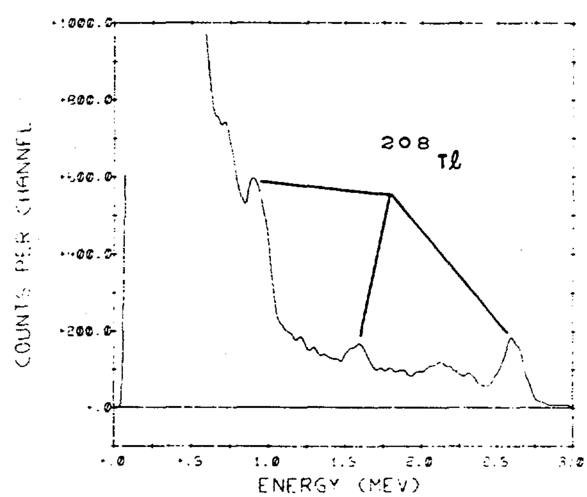

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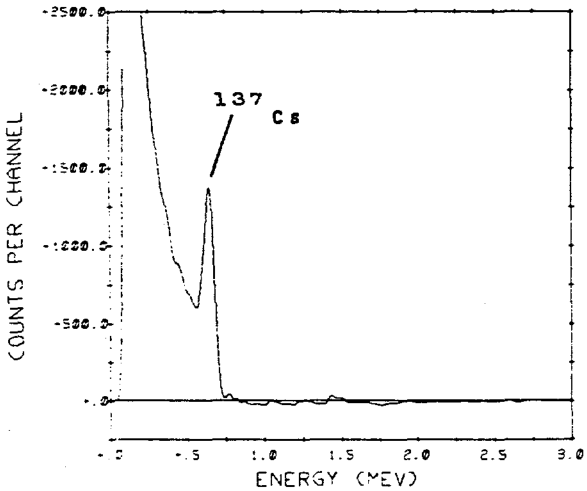

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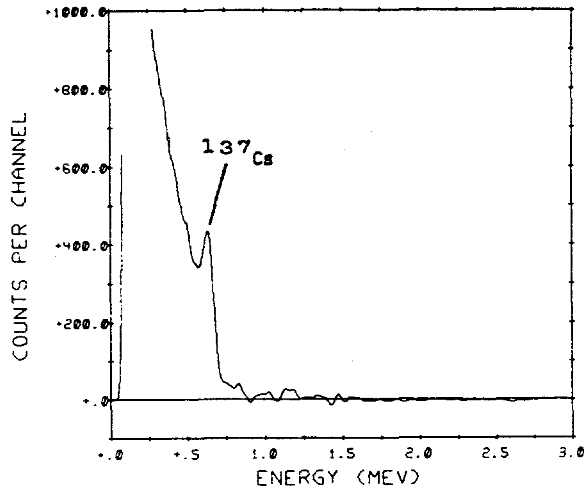

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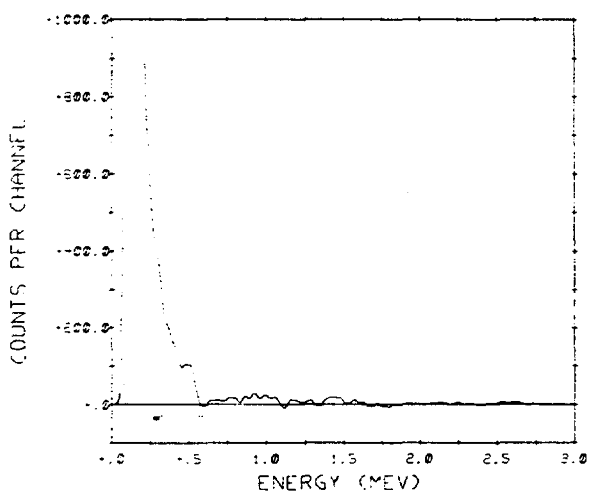

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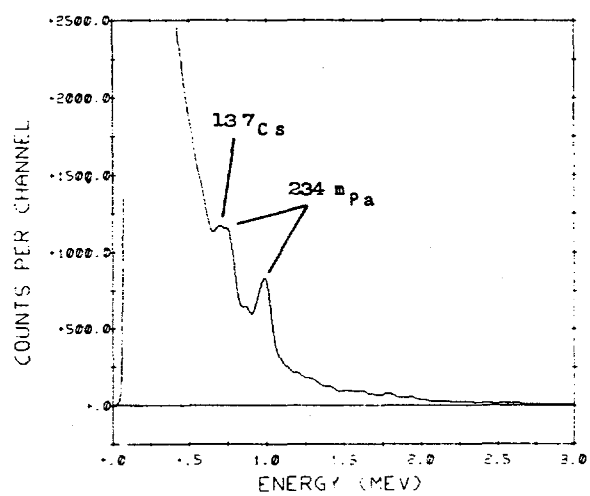

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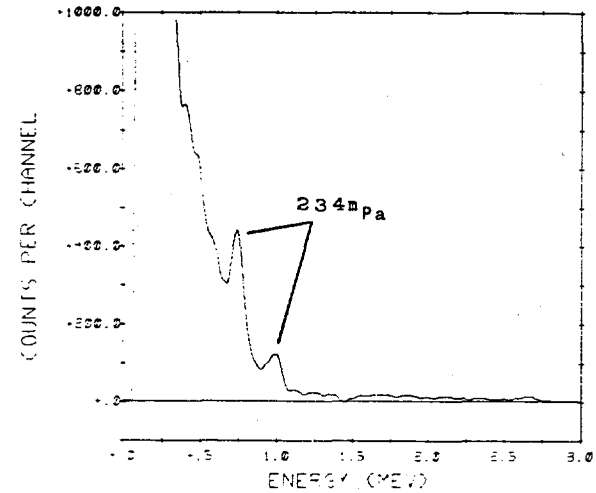

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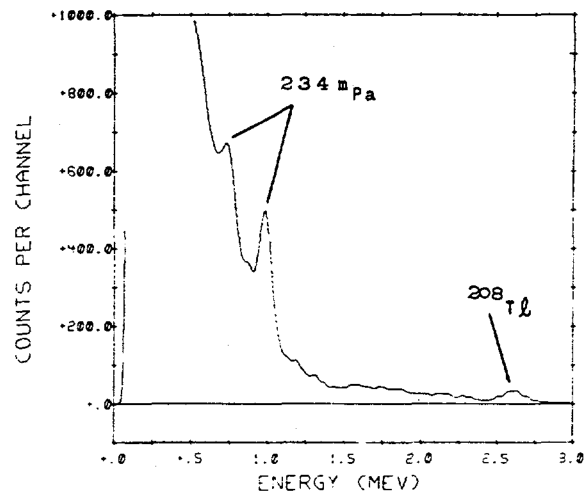

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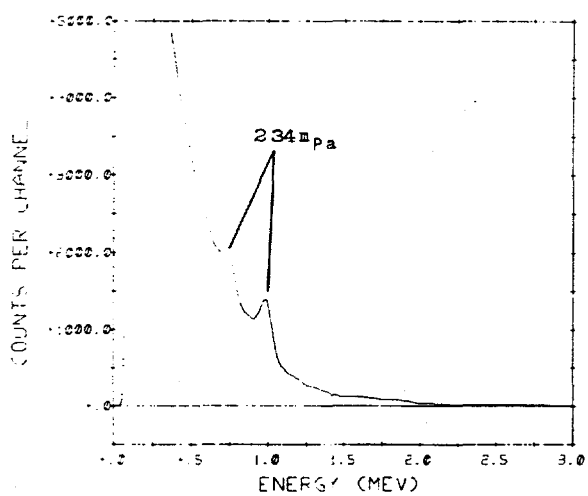

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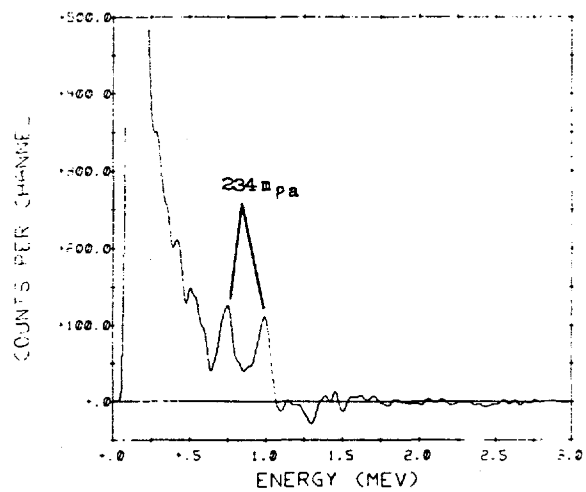

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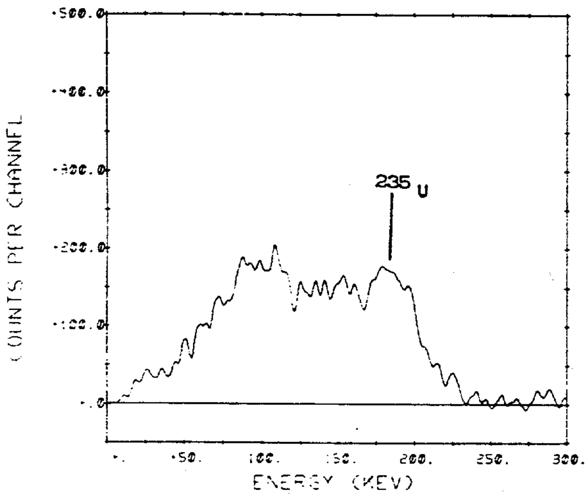

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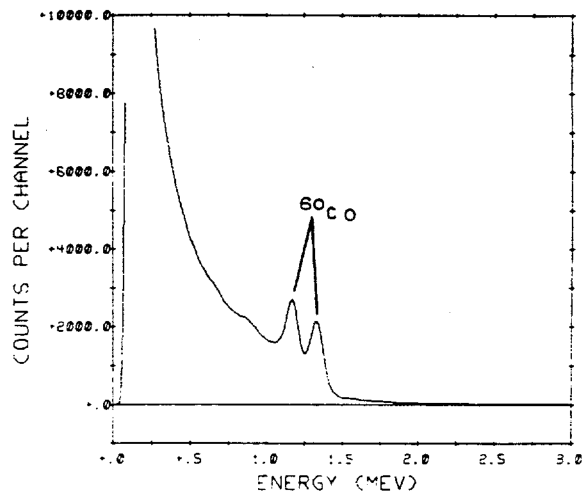

SPECTRUM NO. 42

APPENDIX D. DATA PROCESSING PROCEDURES

During the Oak Ridge surveys, the data acquisition system described in Appendix A recorded more than 350 items of information every 3 seconds. In order to reduce this enormous amount of data to a usable form in a reasonably short time, a computer-based data reduction system (described in Appendix A) was used. Basic information used in most of the data reduction included the following:

Information	Time Resolution
MRS position data	1 sec
INS position data	1 sec
Radar altitude	1 sec
Live time	1 sec
305 channel spectrum (10 keV/channel)	3 sec

Some of the data were processed during the helicopter survey on site to allow preliminary results to be available as soon as possible. The remainder was processed at EG&G's data processing laboratory in Las Vegas.

D.1 Aircraft Position Data

The position of the helicopter was continuously measured and recorded using the microwave ranging system (MRS). The distances between the aircraft and the two remote units were documented on magnetic tape once every second. The system had been calibrated prior to the survey. The distance between the two remote units (Buffalo Mt. and Harriman Fire Tower) was measured by hovering over each of the units and averaging the measured distances. The distance was measured to be 22,095m. The exact position of the helicopter at any point was then computed from simple trigonometry. Position errors were related to the distance parameter (between the aircraft and the remote unit), as well as to the angle between the directions to the remote units at the aircraft position. Details of the relationships are discussed in Ref. 9 and 10. The position accuracy for the helicopter survey of the Oak Ridge site using the MRS position data was about ±15m.

An inertial navigation system (INS) was used to obtain aircraft position data for the fixed wing survey and to supplement the MRS data for the helicopter survey. Before each flight, the INS unit was calibrated by inserting in the proper latitude and longitude coordinates at the airport. Each second during the flight the data acquisition system recorded on magnetic tape the INS position data in latitude and longitude coordinates. As standard procedure for all the surveys, an on-top mark at the beginning and end of each line was placed on the magnetic tape by the navigator as the aircraft passed over certain known locations on the ground. The latitude and longitude coordinates of each on-top mark was determined from a map. These coordinates were compared to those recorded by the INS unit and a drift versus time calculated. The small drift was then accounted for in the computer reduction program.

For the helicopter survey, a combination of MRS and INS data were used in those locations and areas where the hills and ridges blocked the line-of-sight between the helicopter and the MRS remote units.

D. 2 Altitude and Dead Time Correction

Even though the pilots attempted to keep the aircraft as close to a given altitude as possible, small deviations occurred. In order to determine the gamma count rate dependence on altitude, measurements were made as a function of altitude over an area east of the U. T. Farm (Appendix G). The correction factor to be applied to the count rate data was determined to be:

$$\text{Alt. correction factor: } F = e^{-0.0059(A_o - A)} \qquad (1)$$

where

A_o = nominal survey altitude in meters
A = measured altitude above terrain (from radar altimeter) in meters

All of the data, second by second, were adjusted to a nominal altitude by the above equation. The nominal altitude for the fixed wing survey was 150m and for the helicopter survey, 75m.* The same factor was used in correcting all of the count rates from natural radiation, as well as from man-made radiation, including photopeak count rates. The use of multiple factors for various energy values did not seem justified since the altitude deviation was only ± 15m for the helicopter surveys. The use of a single correction factor introduced significant errors only over point sources where the actual altitude was considerably different than the nominal altitude.

The large volume of NaI(Tl) crystals (25,000 cm^3) produced 5,000 to 10,000 counts per second at 75m altitude from gamma radiation emanating from natural radiation in the soil. This count rate produced a few percent dead time in the data acquisition system. All data were corrected for system dead time losses on a second-by-second basis. For exceptionally large count rates (>60,000 counts per second) dead times were large and spectral distortion occurred. In these cases, specific areas and lines were resurveyed with only two detectors activated rather than the usual 40.

D. 3 Natural Terrestrial Radiation Levels

It was of interest to estimate the exposure rates one meter above the ground from natural radioelements existing in the soil. Contributions from worldwide fallout (mostly ^{137}Cs) were also included in this category.

For the airplane survey, non-terrestrial background contributions (from cosmic rays, aircraft background and airborne radon daughters) were determined from (1) data taken over the river; (2) air filter measurements; and (3) results derived from the "dual" detector system.+ These contributions to the gross gamma count rate (.05 to 3.0 MeV) are listed in Table D. 1. The resulting "net" count rate was corrected for live time and altitude deviations, divided into letter

*A small amount of data were normalized to 45-meter altitude.
+See Ref. 6 for details of how air filter and "dual" detector system results can be used to infer airborne radon daughter contributions.

Table D.1 Non-terrestrial radiation contribution to the gamma gross count rate (0.05 to 3.0 MeV); Oak Ridge airplane survey.

Date	Line Number	Contribution (cps)
9/19/73	ALL	1750
9/20/73	ALL	1840
9/21/73	29, 30, 31	3590
	32, 33, 34	3230
	35, 36, 37	3440
	38, 39	3110
	40, 50	2770
	51, 52	2480
9/22/73	53, 54	2840
	55, 56, 57	2670

categories and plotted on a map versus aircraft position so that gamma intensity isopleths could be drawn. Applicable one-meter exposure rates were then assigned to each letter category (see Section D. 5).

For the helicopter survey, non-terrestrial background contributions were determined from data taken over a test line* each day and from data taken over a lake (Appendix G). These contributions are listed in Table D. 2. The average value for the gross count rate (.05 to 3.0 MeV) was 1500 cps and for the upper gross count rate (1.40 to 3.0 MeV), 91 cps. Day-to-day changes were primarily due to changes in airborne radon daughter concentrations. The natural terrestrial radiation levels were determined two ways. First, the net count rate over the entire energy spectrum (.05 to 3.0 MeV) was determined and plotted in appropriate letter categories. The high count rates (~4000 cps) resulted in good spatial resolution for those areas containing only natural radiation. Second, the net count over the upper energy spectrum (1.40 to 3.0 MeV) was determined and plotted in appropriate letter categories. This allowed an estimate of natural radiation intensities to be made over those areas containing man-made radiation.

Results from both the airplane and helicopter surveys were combined and a single isopleth map constructed of the natural terrestrial radiation levels applicable to one meter above the ground (see Section D.5).

D. 4 Spectral Stripping Procedures

The principle isotopes detected during the airborne radiological survey of the Oak Ridge site were ^{40}K, thorium and uranium series (all from natural radiation) and ^{60}Co, ^{137}Cs, and ^{234m}Pa** (produced by man). It was desirable to separate the contributions from natural radioisotopes

*A test survey line about 1700 meters long near Oak Ridge was flown each day to establish repeatability and to observe any changes in the background radiation environment.

**^{234m}Pa is a natural decay product of ^{238}U, but is grouped with man-made radioelements, because detecting its presence indicates man has extracted and brought together large quantities of elemental uranium out of its natural setting.

Table D.2 Non-terrestrial radiation contribution to the gamma gross count rate; Oak Ridge helicopter survey.

	Contribution	
Date	Gross Count Rate (.05-3.0 MeV) cps	Upper Gross Count Rate (1.40-3.0 MeV) cps
11/8/74-AM	1300	89
11/8/74-PM	1350	88
11/9/74-AM	1700	91
11/9/74-PM	1650	100
11/12/74-AM	1520	100
11/12/74-PM	1800	110
11/13/74-AM	1550	98
11/13/74-PM	1350	93
11/15/74-AM	1000	70
11/15/74-PM	1000	70
11/16/74-PM	1500	91
11/21/74-AM	1100	70

from those contributed from man-made radiation in order to determine the location, magnitude and type of gamma radioactivity in the area surveyed. A stripping analysis technique was used to extract the contributions of the individual man-made radioisotopes from the complex spectra.

The nature of the gamma pulse-height distribution as measured by the NaI(Tl) detector array is illustrated in Fig. D.1 Gamma rays from naturally occurring radioisotopes, as well as the dominant man-made contaminants are shown. The counts in each photopeak window generally contain contributions from the Compton tails of higher energy gammas from other isotopes, as well as unresolved uranium and thorium series peaks. Definition of the letter symbols, energy windows, and related isotopes used in this analysis is given in Table D.3. The letter b, with subscripts, refers to the contribution from natural background radiation (including cosmic and aircraft background), Co from Cobalt-60, Pa from proctactinium-234m, and Cs from cesium-137.

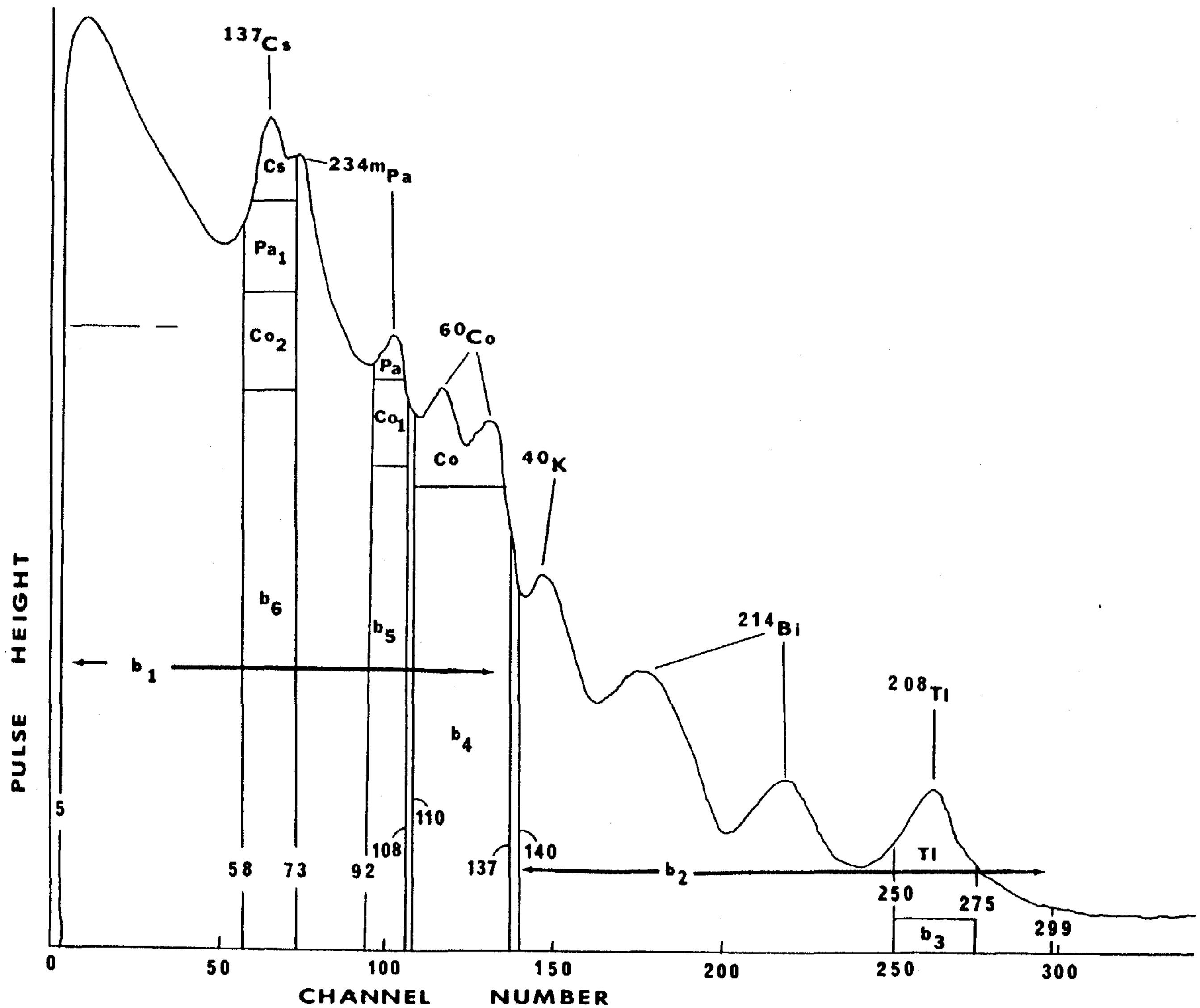

Figure D. 1 Illustrated gamma pulse-height distribution from NaI(Tl) detector array at survey altitude.

Table D.3 Definition of channel windows (10 keV per channel), letter symbols, and related radioisotopes used in derivation of spectral extraction coefficients. (See Fig. D.1)

Symbol	Channel Range of Window	Contribution Definition
b	5 thru 299	gross count from background radiation only
b_1	5 thru 139	lower portion of background gross count
b_2	140 thru 299	upper portion of background gross count
b_3	250 thru 275	background contribution to ^{208}Tl window
b_4	110 thru 137	background contribution to ^{60}Co window
b_5	92 thru 108	background contribution to ^{234m}Pa window
b_6	58 thru 73	background contribution to ^{137}Cs window
Tl	250 thru 275	^{208}Tl photopeak count rate
Co	110 thru 137	^{60}Co photopeak count rate
Co_1	92 thru 108	^{60}Co contribution to the ^{234m}Pa window
Co_2	58 thru 73	^{60}Co contribution to the ^{137}Cs window
Pa	92 thru 108	^{234m}Pa photopeak count rate
Pa_1	58 thru 73	^{234m}Pa contribution to the ^{137}Cs window
MMGC	5 thru 139	gross counts from man-made radiation only
Cs	58 thru 73	^{137}Cs photopeak count rate

D.4.1 Man-Made Gross Counts

One of the most important results of the ARMS surveys has been the extraction of the total gross count rate (relative to the total photon flux density) contributed only by man-made radiation. This term has been designated man-made gross counts (MMGC). The equation used for the extraction of man-made gross counts (MMGC) was:

$$MMGC = (cts_{5-139}) - K_1(cts_{140-299}) \qquad (2)$$

where

$K_1 = b_1/b_2$, for natural radiation only (see Fig. D.1 & Table D.3)

$cts_{n_i - n_j}$ = counts in channels n_i thru n_j

In the data reduction process, the computer applied equation (2) to each flight line, record-by-record, thereby subtracting out the natural background contribution.

The value of K_1 was determined for each area from data taken over lines or portions of lines known not to be contaminated. Its value varied a little from area to area due to changes in composition of the natural radiation contributors. For example, values of K_1 were found to vary from 14.9 over the center of the river where the contribution was primarily cosmic radiation to 19.9 over natural radiation near the HPRR facility. Values* of K_1 used in the data reduction of each of the areas surveyed are given in Table D.4. The value is not sensitive to small changes in altitude, airborne radon daughter contributions or variations in the natural background intensity. This allows the detection of low levels of man-made radiation in the presence of subtle variations in the natural background. In the example given in Fig. D.2 (from Ref. 9), the first and second peaks from man-made radiation on the gross count rate plot are effectively obscured by variations in the natural background. In the absence of man-made sources, MMGC values typically fluctuate about zero with statistically standard deviation of about ±300 cps, whereas the fluctuation of the gross count rate (due to intensity changes) is typically ±1000 cps.

The MMGC extraction routine (Equation 2) will not extract count rates from man-made isotopes having photopeak energies above 1.4 MeV, such as from noble gases, ^{16}N, etc.

It is useful to present the radiation data in the form of isopleths which overlay a map or photograph of the area surveyed. This allows a rapid, visual correlation to be made between the measured activity and its origin on the ground. The isopleths were constructed by plotting, on a second-by-second basis, the radiation data as a function of position after the position information from the MRS and/or the INS was properly scaled for the particular map desired.

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*Values are in excellent agreement with Becks[11] predictions, assuming count-rate is proportional to flux.

Table D. 4. Extraction coefficient, K_1, for data processing of man-made gross count rates, Oak Ridge helicopter survey (see Eq. 2).

Date	Survey Line Numbers	K_1
11/7/74-AM	River & creeks	17.32
11/7/74-PM	River, creeks & islands	17.32
11/8/74-AM	1-22	17.48
11/8/74-PM	23-35	17.48
	Islands	17.32
11/9/74-AM	36-46	18.70
	1A-5A	18.70
11/9/74-PM	47-62	17.73
11/12/74-AM	93-112	17.55
11/12/74-PM	83-92	17.34
11/13/74-AM	69-82	17.54
11/13/74-PM	61-68	18.35
	132-134	18.46
	135-139	17.09
11/15/74-AM	140-142	17.09
	158-163	17.09
	143-150	20.50*
11/15/74-PM	151-157	20.50*
	120-131	18.12
11/16/74-AM	77B-105B	18.77+
11/16/74-PM	113-119	19.93
	Islands	17.32
	171-174	17.03
11/21/74-AM	164-178	17.85
	Boundary	17.85
	120A, 120B	18.12
	113A, 113B	19.93

*Equation (2) modified as follows: $MMGC = (cts_{5-189}) - K_1(cts_{140-249})$, to minimize influence of high thorium source in area.

+Two detectors only.

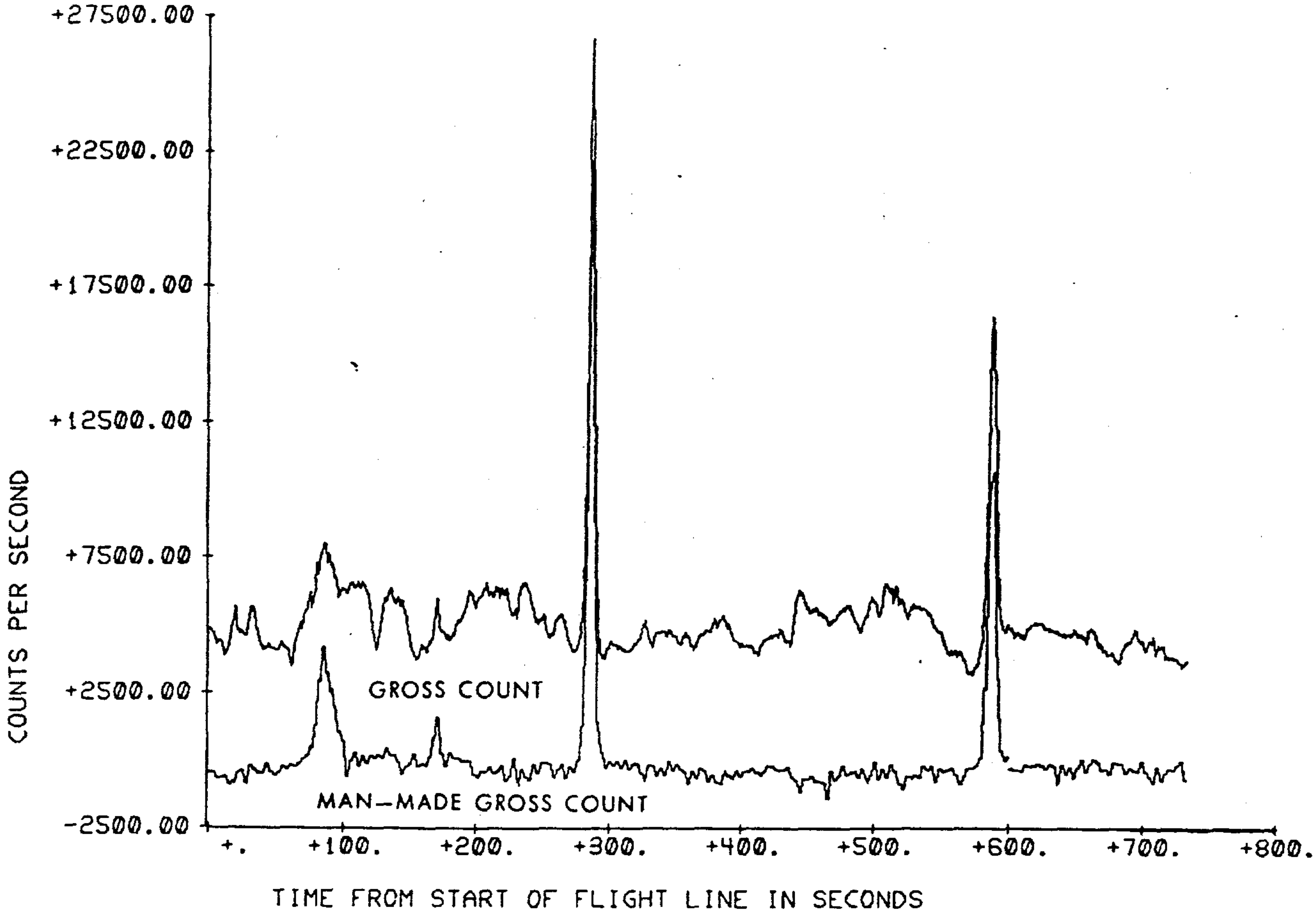


Figure D. 2 Gross count rate and man-made gross count rate (both .05 to 3.0 MeV) from the same survey line; illustrating the effectiveness of pinpointing low-level man-made sources in the presence of fluctuating natural radioactivity.

These distribution plots of MMGC were prepared by programming the computer to assign a radiation intensity code letter to each data record. The first category was chosen to begin at three times the standard deviation, or 900 cps. The letter B was assigned to this category which was 900 to 1800 cps; the letter C to the next category, 1800 to 3600 cps, etc. The alphabetic symbols, designating count rate intervals, were plotted (by the 30-inch CalComp plotter) each second along the survey line with a position uncertainty related to the flying time of ±1/2 second. Even though the spectral data were recorded in 3-second blocks, an excellent approximation to the equivalent 1-second count rate could be obtained by separating the 3-second total into 1-second parts according to the live time, which was recorded every second. Once the MMGC intensities (as letters) were plotted, drafting paper was overlaid on the plots and areas of equal radiation intensity were delineated to construct the MMGC distribution map or radiation isopleth (results are given in Chapter 4).

D. 4. 2 ^{208}Tl Photopeak Count Rates

Since there were areas at Y-12 which appeared to contain large quantities of thorium, it was of interest to process the data over that area for photopeak count rates from ^{208}Tl. Referring to Table D. 3 and Fig. D. 1, the equation used for the extraction of ^{208}Tl photopeak count rates (Tl) was:

$$Tl = (cts_{250-275}) - b_3 \tag{3}$$

where

$cts_{250-275}$ = counts in channels 250 thru 275

b_3 = background contribution (5. 05 cps as determined from lake data)

D. 4. 3 ^{60}Co Photopeak Count Rates

Many of the areas contained ^{60}Co. The equation used for the extraction of ^{60}Co photopeak count rates (Co) was:

$$Co = (cts_{110-137}) - K_2(cts_{140-299}) \tag{4}$$

where

$cts_{n_i-n_j}$ = counts in channels n_i thru n_j

$K_2 = b_4/b_2$ for background radiation only (see Table D. 3 & Fig. D. 1)

Several areas containing only background radiation were examined to obtain the value of K_2. Its value varied from 0. 570 to 0. 610 from area to area. An average value of 0. 586 was chosen to represent all areas and survey lines. All areas were then processed using Equation (4) to derive photopeak count rates from ^{60}Co.

The extraction equation does not account for contributions from ^{208}Tl (from large quantities of thorium) nor from ^{234m}Pa (from large quantities of uranium). The values of K_2 for a ^{208}Tl source was found to be 0.387. Therefore, processing the data by Equation (4) over those areas produced negative values in the ^{60}Co photopeaks. High count rates from the 1.0 MeV peak from ^{234m}Pa produced counts in the ^{60}Co window (1.10 to 1.37 MeV) because of poor resolution in the NaI(Tl) detectors. This did not produce serious problems, however, since the spectral information did not reveal the presence of ^{60}Co in any of those areas containing large quantities of uranium or thorium. Therefore, in drawing the isopleth from the processed data, the spectral data was taken into account.

In those areas where ^{137}Cs produced very high count rates (>60,000 cps), pulse pile-up produced counts in the ^{60}Co photopeak, thereby giving a false indication of the presence of ^{60}Co. Again, the spectral data (as well as the count rate data) were consulted in order to accurately prepare the ^{60}Co isopleth (see Chapter 4).

A small count rate contribution from ^{41}Ar (1.29 MeV) was observed during the survey over the U.T. Farm and Y-12 areas. The spectral data and special count rate plots did not reveal the presence of ^{60}Co in these areas. In drawing the isopleths for both ^{60}Co and MMGC, these data were considered.

D.4.4 ^{234m}Pa Photopeak Count Rates

The isotope of ^{234m}Pa is a decay product of natural uranium. The measurement of its presence indicates the presence of large quantities of ^{238}U, separated from its radium daughter products. Two gamma rays, one at 1.0 MeV and one at 0.75 MeV, reveal its presence. Since ^{60}Co was not present in any of the areas containing ^{234m}Pa, the equation used for the extraction of the 1.0 MeV ^{234m}Pa photopeak count rate (Pa) was:

$$Pa = (cts_{92-108}) - K_3\,(cts_{109-299}) \qquad (5)$$

where

$cts_{n_i n_j}$ = counts in channels n_i thru n_j

and $K_3 = (b_5)/(cts_{109-299})$ for background radiation only (see Table D.3 & Fig. D.1)

Several lines and areas containing only background radiation were examined and a value of K_3 = 0.340 was determined to be adequate for Equation (5). All survey lines over the K-25 and Y-12 areas and the White Wing Scrap Yard were processed to extract the ^{234m}Pa photopeak count rates. Other areas were not processed since the spectral data did not reveal the presence of ^{234m}Pa. Equation (5) worked well even over those areas in Y-12 containing thorium. The value of K_3 for those areas was found to be about 0.35.

D.4.5 ^{137}Cs Photopeak Count Rates

Most of the areas surveyed contained ^{137}Cs. To extract the ^{137}Cs photopeak count rate (Cs), two equations were used. These were:

$$Cs = (cts_{58-73}) - K_4(cts_{74-299}) \tag{6}$$

$$\text{and } Cs' = (cts_{58-73}) - Pa_1 - Co_2 - b_6 \tag{7}$$

where $cts_{n_i - n_j}$ = counts in channels n_i thru n_j

$K_4 = (b_6)/(cts_{74-299})$ for background radiation only

and Pa_1, Co_2 and b_6 as defined in Fig. D.1 & Table D.3

Equation (6) was used for processing the data in those areas containing only ^{137}Cs and in those areas containing low levels of ^{60}Co. Several survey lines and areas containing only background radiation were examined and values of K_4 found to vary from 0.400 to 0.470. A value of 0.419 was found to be adequate. Equation (6) worked well in those areas containing low levels of ^{60}Co (islands) because a value of K_4 over a pure ^{60}Co source was found to be 0.39.

Several areas contained both ^{137}Cs and ^{234m}Pa. Other areas contained both ^{137}Cs and higher levels of ^{60}Co. For these areas, Equation (7) was used to extract the ^{137}Cs photopeak count rates. From the definitions given in Table D.3 and from data taken over areas containing only ^{234m}Pa, only ^{60}Co, and only natural radiation; values of Pa_1, Co_2 and b_6, respectively, were found to be:

$$Pa_1 = 1.976\ Pa \quad \text{for } ^{234m}Pa \text{ source only} \tag{8}$$

$$Co_2 = 0.962\ Co \quad \text{for } ^{60}Co \text{ source only} \tag{9}$$

and $$b_6 = 1.317\ b_2 \quad \text{for natural radiation only} \tag{10}$$

From Equations (4), (5), (8), (9), and (10) and values of K_2 & K_3, Equation (7) can be rewritten as:

$$Cs' = (cts_{58-73}) + 0.304(cts_{140-299}) - 0.962\,(cts_{110-140}) - 1.96(cts_{92-108}) \tag{11}$$

Equation (11) was used to process the data taken over the following areas: K-25, White Wing Scrap Yard, Y-12, X-10, and White Oak Lake.

D.4.6 Other Photopeak Analysis

The results of the low energy (5 to 300 keV) survey were analyzed to look for ^{241}Am and ^{235}U. The gain of the analyzer was set at 1 keV per channel. Three stripping equations were used as follows:

$$\text{Low energy MMGC} = (cts_{20-199}) - 3.55(cts_{200-300}) \tag{12}$$

$$^{241}Am \text{ photopeak count rates} = (cts_{50-69}) - (cts_{40-49}) - (cts_{70-79}) \tag{13}$$

$$^{235}U \text{ photopeak count rates} = (cts_{166-204}) - 0.636(cts_{205-300}) \tag{14}$$

The constants (3.55 and 0.636) in Equations (12) and (14) were derived from data taken over areas known not to contain any man-made radiation. The process for extracting ^{241}Am photopeak count rates assumes that the shape of the spectrum between 20 and 80 keV does not change except when ^{241}Am (60 keV photopeak) is present. The analysis process is described elsewhere.[7]

All of the data taken during the low energy survey were processed using the above equations. Positive values were found over only two areas, the White Wing Scrap Yard and the U. S. Nuclear Fuel Fabrication Facility (see Chapter 4 & Appendix F).

D.4.7 Summary of Data Processing Equations and Count Rate Categories

From the information presented in the above sections, a summary of the data processing equations, stripping constants, and count rate letter categories are given in Table D.5. In general, the count rate intervals increase a factor of 2 progressively from B to O categories. The exceptions are the natural and ^{208}Tl categories where smaller intervals were chosen in the lower levels.

D.5 Application to Surface Situations

D.5.1 Exposure Rates

Ionization in air is a common measure of the gamma radiation levels at a given location. It has been useful to relate the airborne measurements to an equivalent exposure rate one meter above the ground. A single factor converting gross counts per second at survey altitude to an equivalent exposure rate one meter above the ground has been found to be adequate for sources distributed in the soil over large areas having gamma-ray energies above 500 keV. The conversion is applicable only when the area of interest is large, since the aerial survey results represent averages over large areas on the ground. It is particularly applicable for natural radiation levels. Direct comparisons of airborne surveys to results of ground surveys, however, is not trivial, since a multitude of ground-based measurements are necessary to obtain an average over the same area as the airborne results. For a 90% contribution from an infinite plane source (mixed in the soil), the areas sampled by an airborne detector are about 300m in diameter for a 45m height, and about 400m in diameter for a 75m height and about 600m in diameter for a 150m height.[12] More extensive discussions of exposure rate correlations with airborne results can be found in the literature.[13,14] Direct application to the Oak Ridge survey will be discussed here.

Table D. 5. Spectral stripping equations and count rate intervals for Oak Ridge Helicopter survey.

Natural gross count rate = $(cts_{5-299}) - K$; $K = 1000$ to 1800 (15)

Upper gross count rate = $(cts_{140-299}) - K'$; $K' = 70$ to 110 (16)

MMGC = $(cts_{5-139}) - K_1(cts_{140-299})$; $K_1 = 17.03$ to 19.93 (17)

$^{208}Tl = (cts_{250-275}) - 5.05$ (18)

$^{234m}Pa = (cts_{92-108}) - 0.34(cts_{109-299})$ (19)

$^{60}Co = (cts_{110-137}) - 0.586(cts_{140-299})$; 40 detectors (20)

$^{60}Co' = (cts_{110-137}) - 0.712(cts_{140-299})$; 2 detectors (21)

$^{137}Cs = (cts_{58-73}) - 0.419(cts_{74-299})$ (22)

$^{137}Cs' = (cts_{58-73}) + 0.304(cts_{140-299}) - 0.962(cts_{110-140}) - 1.96(cts_{92-108})$ (23)

COUNT RATE INTERVALS FOR OAK RIDGE HELICOPTER SURVEY

	Gross Count Rates (cps)		Photopeak Count Rates (cps)			
Letter	Natural	MMGC	^{60}Co	^{137}Cs	^{234m}Pa	^{208}Tl
A	<1,400	<900	<50	<70	<40	<30
B	1,401-2,800	901-1,800	51-100	71-140	41-80	31-40
C	2,801-4,200	1,801-3,600	101-200	141-280	81-160	41-50
D	4,201-5,600	3,601-7,500	201-400	281-560	161-320	51-60
E	5,601-7,000	7,501-15,000	401-800	561-1,120	321-640	61-75
F	7,001-8,400	15,001-30,000	801-1,600	1,121-2,240	641-1,250	76-150
G	8,401-10,500	30,001-60,000	1,601-3,200	2,241-4,480	1,251-2,500	151-300
H	10,501-14,000	60,001-120,000	3,201-6,400	4,481-8,960	2,501-5,000	301-600
I	14,001-27,000	120,001-240,000	6,401-12,500	8,961-17,920	5,001-10,000	601-1,200
J	27,001-67,500	240,001-500,000	12,501-25,000	>17,920	10,001-20,000	1,201-2,500
K	67,501-135,000	500,001-1,000,000	25,001-50,000		20,001-40,000	>2,500
L	135,001-270,000	>1,000,000	50,001-100,000		>40,000	
M	270,001-675,000		100,001-200,000			
N	675,001-1,350,000		200,001-400,000			
O	>1,350,000		>400,000			

D. 5. 1. 1 Airplane Survey

Using the same detector systems as used in the Oak Ridge airplane survey, flights were made over a natural radiation calibration range near Las Vegas.[13] After accounting for non-terrestrial gamma radiation contributions, a 1 μR/h exposure rate 1m above the ground was found to produce a gross gamma count rate (.05 to 3.0 MeV) of 544 counts per second in the primary detector system at an equivalent air mass thickness of 16.0 g/cm^2 (about 150m above the ground).

The average temperature during the airplane survey of the Oak Ridge area was 24.7 °C and the average pressure was 718mm of mercury. Since the nominal altitude was 150m, the nominal air mass thickness was 17.08 g/cm^2. At this air mass thickness, an exposure rate of 1 μR/h 1m above the ground would produce a gross gamma count rate of 513 cps. This conversion factor was applied to all the gross count rate data from the airplane surveys.

D. 5. 1. 2 Helicopter Survey

Using the same detector systems as used in the Oak Ridge survey, mounted outside a UH-1N helicopter, surveys were made over a natural radiation calibration range near Las Vegas. After accounting for non-terrestrial contributions, a count rate of 966 cps (0.05 to 3.0 MeV) at 16.0 g/cm^2 air mass thickness was found to result from an exposure rate equal to 1 μR/h 1m above the ground. The average temperature during the helicopter Oak Ridge survey was 8.2 °C and the average pressure was 753mm of mercury. Most of the surveys were made at a nominal altitude of 76m. The nominal air mass thickness was then 9.5 g/cm^2. Knowing the dependence of count rate on air mass thickness above the ground (Appendix G), a count rate of 1350 cps at 9.5 g/cm^2 would result from an exposure rate of 1 μR/h 1m above the ground. This conversion factor was valid for natural terrestrial radiation.

It was of interest to estimate an equivalent one meter exposure rate resulting from only man-made radiation as measured by the airborne surveys. Two conditions will be considered. Isotopes uniformly distributed (vertically and horizontally) in the soil will be considered first. Beck[11] has calculated ratios of gamma flux densities at survey altitudes to exposure rates one meter above the ground for natural radioisotopes and for ^{137}Cs. The conversion factors for natural terrestrial radiation (the above value of 1350) was measured over a calibration range dominated by thorium. Assuming that MMGC is proportional to photon flux and that conversion factors for ^{60}Co and ^{40}K are essentially the same, the following conversion factors were estimated: (1) for ^{137}Cs, a MMGC rate at 75m altitude of 1380 cps $\cong$ 1 μR/h at 1m above the ground; (2) for ^{60}Co, a MMGC rate of 1200 cps $\cong$ 1 μR/h at 1m above the ground.

For isotopes on the surface another approach was taken. From infinite plane theory[15, 16] assuming ^{60}Co or ^{137}Cs uniformly distributed on an infinite plane (rough ground) an exposure rate of 1 μR/h at 1m above the ground is reduced to 0.44 μR/h at 75m for ^{137}Cs and to 0.5 μR/h for ^{60}Co. From calibration measurements (described in Section D.5.2) a MMGC rate of about 2760 and 1750 cps resulted from an exposure rate of 1 μR/h at the helicopter detector package from a ^{137}Cs and ^{60}Co source, respectively, located about 75m below the detectors. These would result in air-to-ground conversion factors of 1215 (0.44 x 2760 for ^{137}Cs) and 875 (0.5 x 1750 for ^{60}Co) cps from MMGC at 75m equal to 1 μR/h 1m above the ground.

The four conversion factors derived in the above two paragraphs (1380, 1200, 1215 & 875) were averaged to obtain a single value of 1170 cps at 75m indicating 1 μR/h 1m above the ground for gross gamma count rates contributed only by man-made radiation. This value was applied to all MMGC rate intervals to indicate the range of exposure rates resulting from only man-made radiation. Using the same approach a value of 1470 cps at 45m per μR/h at 1m was used. The resulting 1m exposure rates are applicable only as the average exposure rates over the entire field of view of the airborne detectors which is about 400m in diameter. The uncertainty of using a single conversion factor is probably within ± 50% due to cps to flux density uncertainties, directional response of the detectors and due to isotope distribution in the soil.

A <u>much</u> greater uncertainty in applying airborne data to surface situations is the fact that man-made radiation does not usually exist uniformly on an infinite plane, but is usually very localized. To infer exposure rates at a single location 1m above contaminated ground limited in extent, Ref. 16 was used. Table D.6 contains the relationship between the exposure rate at a single location 1m above a contaminated circular area on the ground to the average exposure rate derived by the above method. The values are applicable to both ^{60}Co and ^{137}Cs.

The values should hold reasonably well for other isotopes having gamma ray energies above 500 keV. The values in the table are based on an assumption of uniform surface concentrations with a factor of 2 reduction at 1m due to ground roughness effects. As an application example, an F category for MMGC ranges from 15,001 to 30,000 cps as measured at 75m. The average 1m exposure rate then is 13 to 25 μR/h. If the area is uniformly contaminated and only 50m in diameter, the exposure rate at a single location in the center would be from 90 to 175 μR/h.

Table D.6. Ratio of exposure rates 1m above the center of contaminated circular areas to average 1m exposure rates derived from airborne surveys at altitude h.

Radius of Contaminated Circular Areas*	Conversion Factors**	
	h = 45 meters	h = 75 meters
25 m	10	20
50 m	4	7
100 m	1.9	2.7
200 m	1.4	1.4
500 m	1.0	1.0
∞	1.0	1.0

*Uniform surface contamination of ^{60}Co or ^{137}Cs.
** Ground roughness reduction of 0.5 for 1m exposure rates.

D.5.2 Isotope Concentrations

During the helicopter survey of ERDA's Hanford Reservation,[17] calibrated ^{137}Cs sources were placed on the ground and measurements made at 45m altitude directly above the sources and at horizontal ranges up to 365m. Using Equation (6), the calibration data were processed to extract the ^{137}Cs photopeak count rates. Using radiation transport theory, the unscattered photon flux density was calculated at the detectors. The effective area for the ^{137}Cs photopeak count rate was found to vary from 2400 cps per photon/cm^2-sec directly over the sources (0°) to about 2300 at an angle of 45° and to about 1200 at 80°.

During the helicopter survey of ERDA's Savannah River site,[9] a calibrated ^{60}Co source was hung 6m below one of the detector packages for a calibration flight. At another experiment at EG&G Las Vegas, calibrated ^{60}Co sources were placed near the ground at distances ranging up to 150m and measurements made by one of the detector packages, also placed near the ground. Exposure rate measurements were also made with a calibrated ion chamber. Using Equation (4), the calibration data were processed to extract the ^{60}Co photopeak count rates. The effective area (for both detector packages) for the ^{60}Co photopeak count rate was found to be 1000 cps per photon/ cm^2-sec for the sources placed in a direction normal to the crystal faces.

Using the above measured effective areas, efficiencies and photofractions of NaI(Tl) crystals,[18] and estimating the attenuation provided by the detector packaging material, the following effective areas were estimated for gamma ray energies of interest:

Photopeak Energy (MeV)	Estimated Photopeak Count Rates per photon/cm^2-sec (cps)
0.185	4000 ± 1000
0.662	2300 ± 300
1.00	1500 ± 300
1.25	1000 ± 300
2.62	800 ± 300

Knowing the source activities for the calibration experiments mentioned and assuming the helicopter to be 75m above the ground, conversions of photopeak count rates at altitude to equivalent point source activities on the surface were estimated to be as follows:

Horizontal Range from Point Source (m)	Photopeak Count Rate (cps) at 75m altitude per mCi (Point Source) on the Surface ^{137}Cs	^{60}Co
0	45	60
30	35	50
60	22	30
90	11	20
150	2.1	6.5
230	0.43	2.1
300	0.13	0.8

These data were useful in estimating equivalent unshielded source activities existing in some of the areas of interest.

The calibration data were also processed for MMGC. The exposure rates were calculated at the detectors for ^{137}Cs, and measured for ^{60}Co. Average conversion values of 2760 and 1760 cps (MMGC) per $\mu R/h$ at the detector packages were derived for ^{137}Cs and ^{60}Co sources, respectively, when the sources were 75m below the detector packages.

The exposure rates 1m above the ground can also be inferred from the photopeak data if the source distribution is known. From conversion values given in Beck[19] and the calculational methods given by Tipton,[17] Boyns,[9] and Jobst,[10] the following values are applicable for the photopeak data for the helicopter survey at Oak Ridge:

Source	Assumed Source Distribution	Photopeak Count Rate (cps) at 75m per $\mu R/h$ at 1m — Detector Response: Isotropic	Cosine	Average
^{137}Cs	Planar	150	81	130
	Uniform	180	117	
^{60}Co	Planar	65	33	60
	Uniform	88	56	

The planar distribution involves the assumptions of a surface concentration which is smooth and infinite in extent. The other limiting case (in vertical distribution) involves the assumption of uniform distribution of the radioisotopes in the soil, both vertically and horizontally. The two limiting cases for the detector response are: isotropic (uniform response for all directions) and cosine (response decreases to zero at $\theta = 90^\circ$ as $\cos\theta$; where $\theta = 0^\circ$ in a direction normal to the crystal faces). The exposure rates derived from the photopeak data were compared to the exposure rates derived from the MMGC data over those areas containing only ^{137}Cs and only ^{60}Co and the results found to be internally consistent.

To obtain an equivalent surface concentration in $\mu Ci/m^2$, the 1m exposure rates could be multiplied by 0.094 for ^{137}Cs and 0.023 for ^{60}Co (Ref. 19).

In all cases where radiation data on the surface (exposure rates, isotope concentrations, etc.) are inferred from the airborne data, the surface data apply to the <u>average</u> condition over the entire field of view of the airborne detector, which is about 400m in diameter for a 75m altitude.

Additional information is provided in Table D.7 to allow a variety of results to be obtained from the airborne data.

Table D.7 Conversion Factors for Airborne Survey Results

To convert	into	Multiply by
1m exposure rates from MMGC data as in the isopleth maps	Exposure rates 1m above center of localized contaminated area	Conversion factors in Table D.6
(Same as above)	Exposure rates at survey altitude	0.5
(Same as above)	Man-made gross count rates at survey altitude	1170 (see also Table D.5 & letter categories)
Flux density values as in the isopleth maps	Photopeak count rates at survey altitude	4000 for ^{235}U (0.185 MeV) 2300 for ^{137}Cs (0.662 MeV) 1500 for ^{234m}Pa (1.00 MeV) 1000 for ^{60}Co (1.25 MeV) 800 for $^{208}T\ell$ (2.62 MeV) (see also Table D.5 & letter categories)
1m exposure rates from ^{60}Co or ^{137}Cs isopleth maps	equivalent average surface concentrations in $\mu Ci/m^2$	0.094 for ^{137}Cs 0.023 for ^{60}Co
Letter categories in isopleth maps	gross estimate of apparent total activity within a given area	(see Fig. D.3)

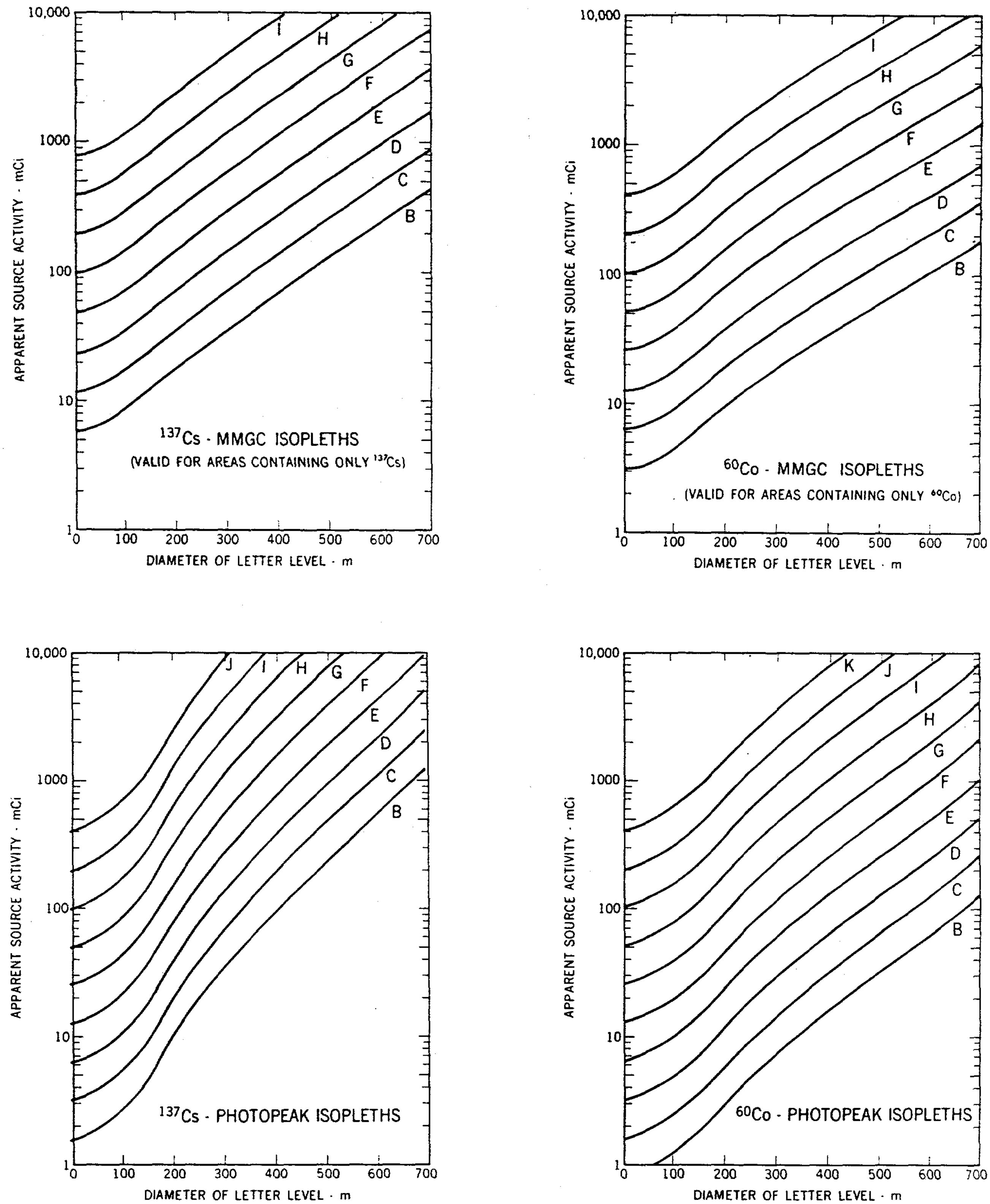


Figure D. 3. Apparent, unshielded, surface activity versus diameter of letter level in isopleth drawings – flight altitude, 75m. Oak Ridge ARMS Survey.

APPENDIX E. GROUND-BASED MEASUREMENTS

During the airplane survey in September 1973, several ground-based measurements were made to correlate with the airborne results. Four locations were chosen in areas where the natural radiation levels were reasonably uniform and the topography was reasonably flat. Exposure rate measurements at one meter above the ground was made by a large ion chamber (Reuter Stokes RS 111). Survey meter readings were made in the vicinity to assure uniformity of radiation levels. Several soil samples at each location were also made.

A summary of the results are given below:

Location*	Terrestrial Radiation Exposure rates in μR/h at 1m calculated from measured soil samples†					Ion Chamber Measurements	from Airborne Results
	^{40}K	^{238}U	^{232}Th	^{137}Cs	Total		
1	0.98	1.55	2.33	0.23	5.1	6.2	4-6
2	0.57	1.49	1.92	0.25	4.2	5.5	2-4
3	0.98	1.24	2.02	0.31	4.6	6.0	4-6
4	0.46	1.75	2.05	0.35	4.6	5.6	2-4

The agreement is satisfactory. The ion chamber results, the soil sample results and the airborne results all contain an error of about ±1 μR/h. The airborne results are representative of averages over the entire field of view which is about 600m in diameter. The ion chamber measurement is applicable to the single location. The soil sample results were averages of 5 samples taken in a 200m diameter area.

* Location 1: near Bethel Rd, 5.2 km east of DOSAR Rd.
Location 2: Between mile 34 & 36, Clinch River U-Turn.
Location 3: Oak Ridge golf course.
Location 4: 1.6 km east of Y-12.

† Conversion factors according to Beck[11], assuming uniform distribution.

Several ground-based measurements have been made in the Oak Ridge Area by ORNL.* A few locations where ion chamber measurements were made were identified and their results compared to the airborne results. The comparison is given below:

Location	Ion Chamber Measurements μR/h	From Airborne Results μR/h
Golf Course Area	5.67, 5.42	4-6
CARL Site	4.54	2-4
Gallaher Bridge Area	3.41, 4.62	2-4, 4-6

*Personal communications, H. W. Dickson, ORNL, 1975.

APPENDIX F. NON-ERDA AREAS

Two areas where man-made radiation levels were observed were not related to ERDA activities. These are described in this appendix.

F. 1 U. S. Nuclear Plant Site

A commercial ^{235}U fuel fabrication facility is located in Bear Valley about 1.8 km east of the Clinch River. This valley was surveyed for low energy (0 to 300 keV) on November 20, 1974, at an altitude of 45m and 90m survey line spacings.

The data were processed for low energy contribution from photopeaks below 200 keV. Positive values were observed over the fabrication plant (Fig. F. 1). A spectrum over the plant site (line 52A) revealed a photopeak at 185 keV (Spectrum No. 41, Appendix C), identifying the presence of ^{235}U below.

F. 2 American Nuclear Site

An area across the river, directly Northeast of the Oak Ridge Marina, was known to contain ^{60}Co contamination. Since it was within five miles of ERDA's boundary, it was surveyed. Eight survey lines in an east-west direction and four lines in a north-south direction (to cover the islands) were surveyed 90m apart at 75m altitude. The survey was conducted between 10:30 and 11:30 am on November 21, 1974. The Melton Hill Lake water level was 241.9m above sea level.

The man-made gross count rate levels (Fig. F. 2) due exclusively to ^{60}Co (see Spectrum No. 42) revealed a G level directly over the building and over the lagoon and an F level between the two. Contamination up to a D level also existed on the islands.

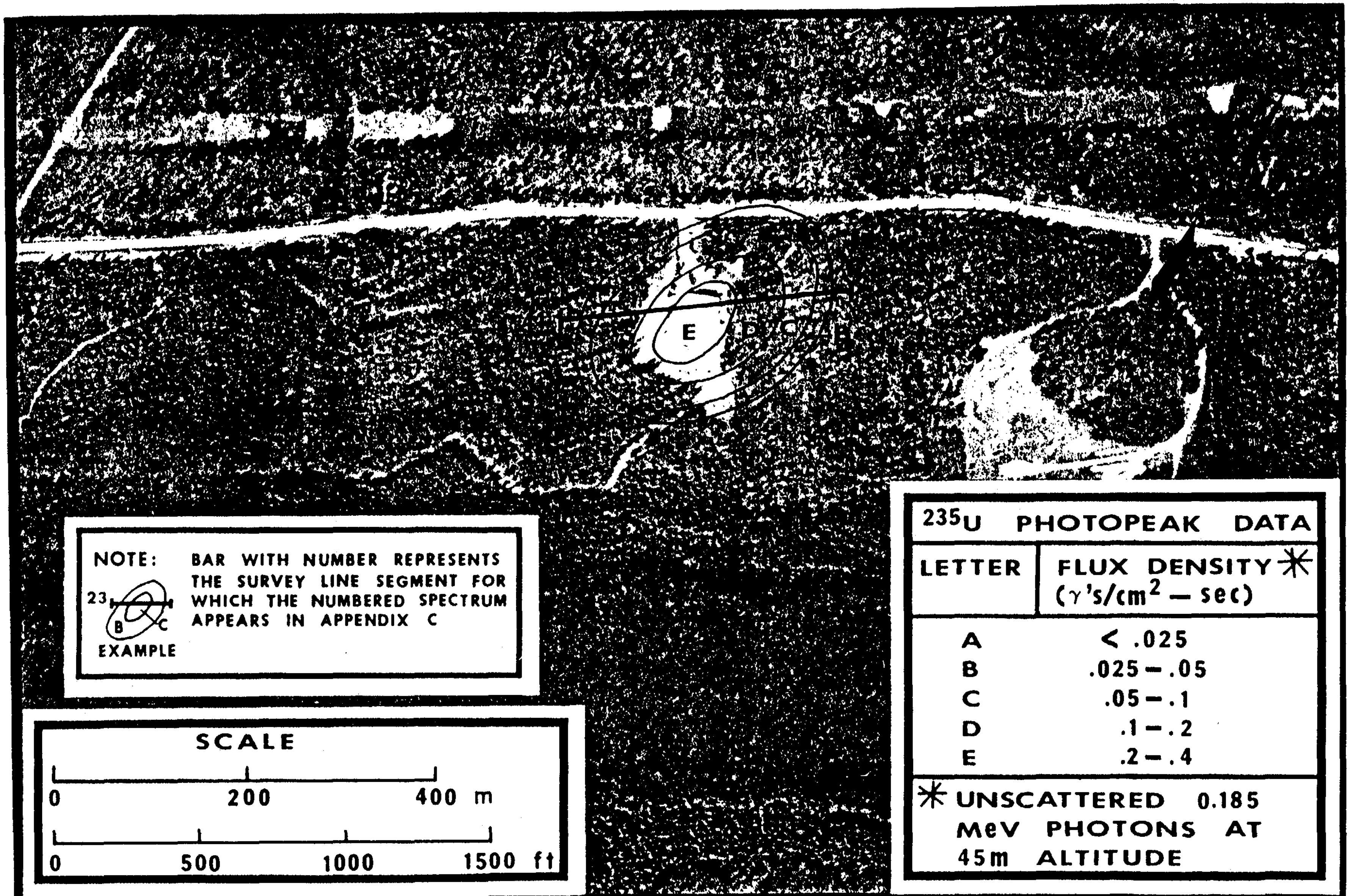


Figure F. 1. Radiation levels resulting from only ^{235}U, inferred from helicopter survey data taken at 75m altitude, Nov 20, 1974, of the U.S. Nuclear fuel fabrication facility, Oak Ridge.

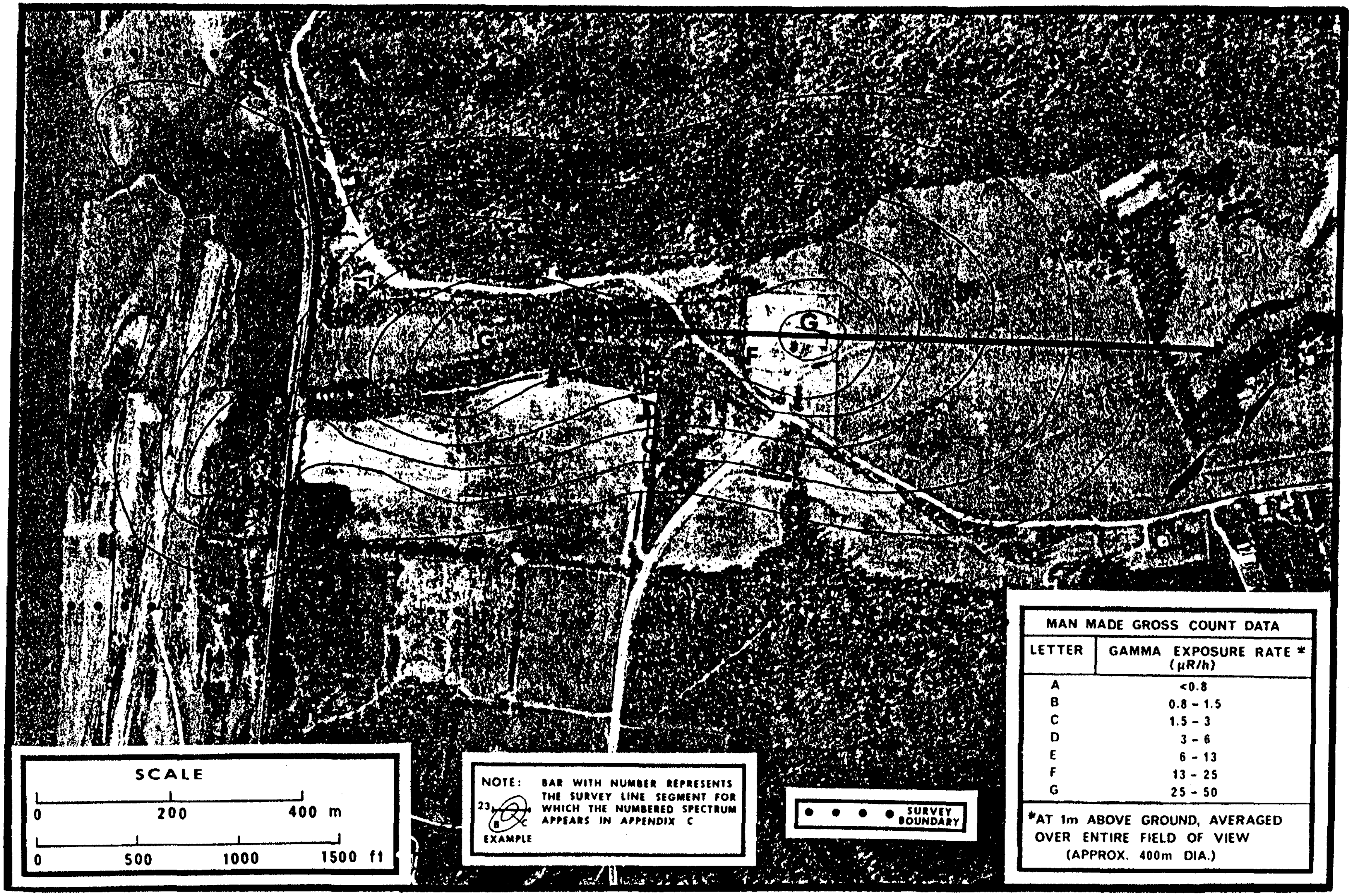


Figure F.2. Radiation levels resulting from only man-made radioisotopes (^{60}Co), inferred from helicopter survey data taken at 75m altitude, Nov 21, 1974, of the American Nuclear Site, Oak Ridge. Natural radiation levels vary from 5 to 10 μR/h (includes cosmic radiation).

APPENDIX G. SPECIAL RESULTS

G. 1 Survey Test Line Data

A survey test line was flown at 150m altitude during each mission to establish repeatability and to observe any changes in the background radiation environment. The survey line was about 1700m long and was located along the Oak Ridge Turnpike. A summary of some of the gamma count rate results is listed below:

Date	Gross Count Rate* (.05 to 3.0 MeV) cps	Upper Gross Count Rate* (1.40 to 3.0 MeV) cps
11/8/74-1	6728 ± 780	383 ± 46
11/8/74-2	6816 ± 891	382 ± 53
11/9/74-1	7244 ± 769	
11/9/74-2	7085 ± 886	397 ± 51
11/12/74-1	6967 ± 846	394 ± 52
11/12/74-2	7811 ± 918	431 ± 74
11/13/74-1	6985 ± 839	392 ± 53
11/13/74-2	6783 ± 806	387 ± 50
11/15/74-1	6296 ± 848	351 ± 54
11/15/74-2	6065 ± 865	343 ± 58
11/16/74-2	6948 ± 830	387 ± 54
11/21/74-1	6386 ± 886	354 ± 55

*Normalized to 75m altitude for convenience.

The gross count rate varied from a low of 6065 cps to a high of 7811 cps. The changes were attributed to changes in radon daughter concentrations in the air. These data were used to estimate the non-terrestrial background contributions to the gross count rates in the data processing.

G. 2 Lake Altitude Spiral Data

On November 16, 1974, measurements were made at several altitudes above the Tennessee River at a location where the river was wide enough such that minimal terrestrial radiation reached the detectors. The purpose was to obtain a non-terrestrial radiation contribution to the detector systems. A summary of the data is listed below:

Alt. (m)	Avg counts per second within designated energy windows .05 to 3.0 MeV	1.4 to 3.0 MeV	1.4 to 1.55 MeV	1.65 to 1.85 MeV	2.5 to 2.75 MeV
30	1145	77.3	23.9	18.4	5.55
60	1243	79.8	25.6	19.0	5.92
90	1336	84.9	26.4	20.8	5.53
120	1390	90.0	27.7	22.7	5.87

G. 3 Altitude Spiral Data Over Land

On the first day of the helicopter survey measurements were made versus altitude over a location just east of the University of Tenn. farm area. The gross count data (.05 to 3.0 MeV) are summarized below:

Average Radar Altitude (m)	Air Mass Thickness (g/cm^2)	Average Gross Count Rate (cps)	Net Gross* Count Rate (cps)
46.6 ±1.1	5.80	7310 ±198	6310
56.7 ±2.2	7.07	6871 ±98	5871
89.3 ±1.4	11.13	5896 ±125	4896
158.5 ±4.3	19.76	4169 ±197	3169
204.2 ±6.7	25.45	3539 ±106	2539

*Assumes a non-terrestrial background contribution of 1000 cps.

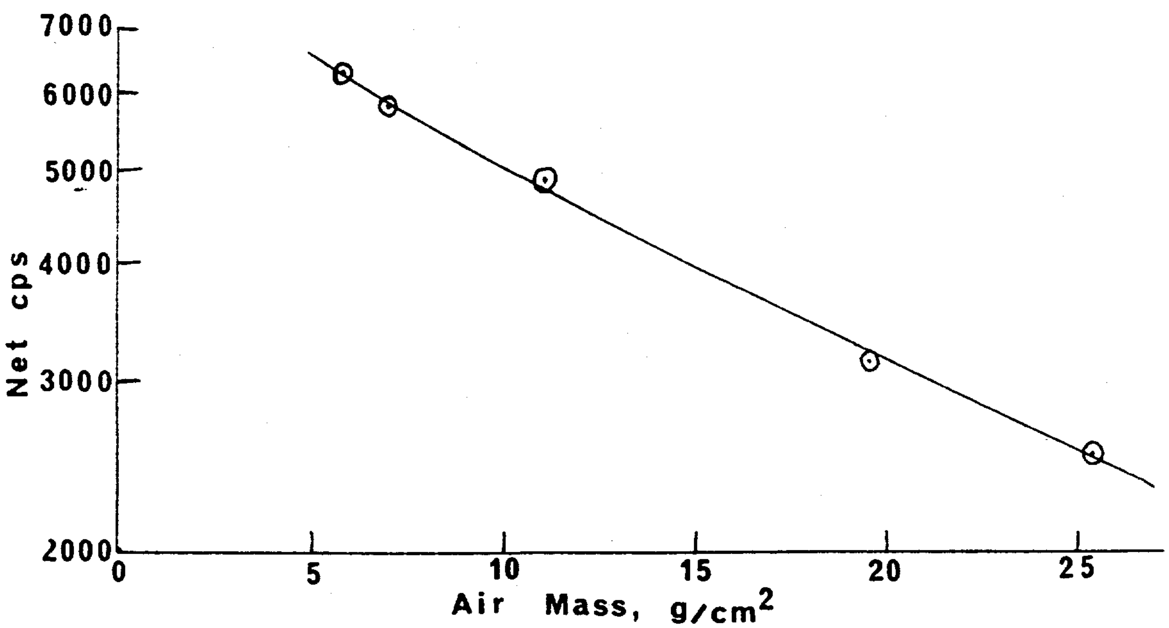
From the above data, an altitude correction factor* was derived as follows:

$$\text{Alt. correction factor: } F = e^{-0.0059(A_o - A)}$$

where

A_o = nominal survey altitude in meters
A = measured altitude above terrain (from radar altimeter) in meters

It is recognized that the count rate is more correctly dependent on air mass thickness than on linear altitude. However, in the data reduction process, it was much more convenient to normalize to a nominal altitude rather than to a nominal air mass thickness. A plot of net count rate versus air mass is shown below.



*A multiplication factor to normalize the count rate data to an equivalent count rate at the nominal altitude.

G. 4 High-Energy Anomaly

On 7 November 1974 during the ARMS Oak Ridge survey, a high-energy gamma ray anomaly was observed in the count rate data. The 40-crystal array (5-in. x 2-in. NaI detectors), mounted outside a UH-1N helicopter, was being flown at 45m above the terrain, following the shoreline of the Clinch River.

Gross count rate data (0.05 to 3.00 MeV) versus time is shown in Fig. G.4.1. The peak at about 10,000 cps shows the anomaly. The enhanced count rate began at about 1218 pm (EST), and lasted for about 50 seconds. The location was near Melton Hill Dam.

The count rate in the cosmic ray energy window (2.76 to 3.06 MeV) is shown in Fig. G.4.2. The average of the first 75 seconds of data is 4.4 cps which is normal for that area. It can be seen that the enhanced count rate reached about 20 times normal. In comparing Fig. G.4.1 and G.4.2, the higher energy component appears to have two peaks and the gross count only one peak.

In order to see if any of the gross count enhancement was caused by terrestrial radiation, net count rates from terrestrially produced ^{208}Tl is given in Fig. G.4.3. The following equation and stripping coefficients were used:

$$^{208}\mathrm{Tl} = (\mathrm{cts}_{250-275}) - 0.95\,(\mathrm{cts}_{276-305}) - 2.09 \qquad (1)$$

One can see from Fig. G.4.3 that the terrestrial ^{208}Tl gamma component is not high. Actually, the values are about half of those found over land (20 to 30 cps). This is consistent with the fact that the shoreland was being surveyed.

A man-made gross count rate plot was made of the data and the result is given in Fig. G.4.4. The equation and stripping coefficient used was:

$$\mathrm{MMGC} = (\mathrm{cts}_{5-139}) - 17.32\,(\mathrm{cts}_{140-299}) \qquad (2)$$

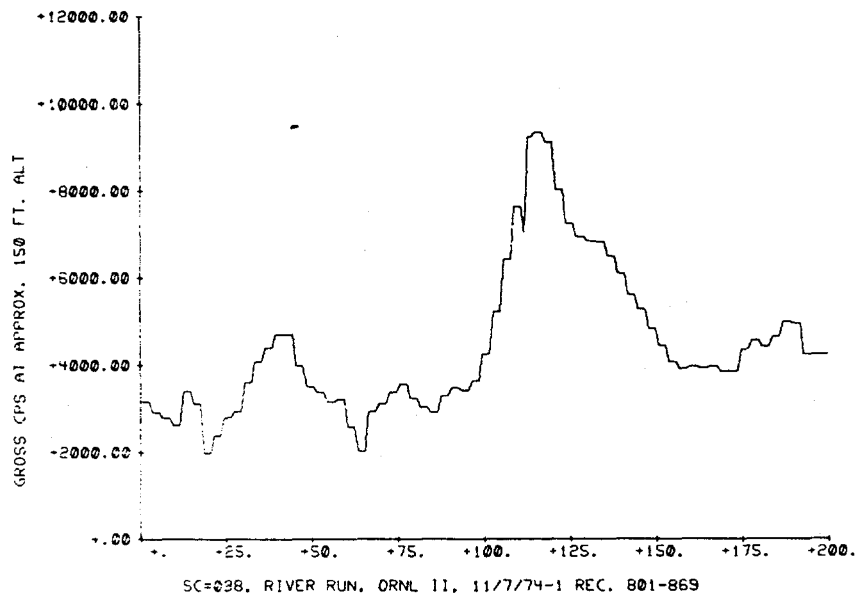


Figure G.4.1 Gross gamma count rate (0.05 to 3.0 MeV) versus time, 40-crystal array mounted on UH-1N helicopter.

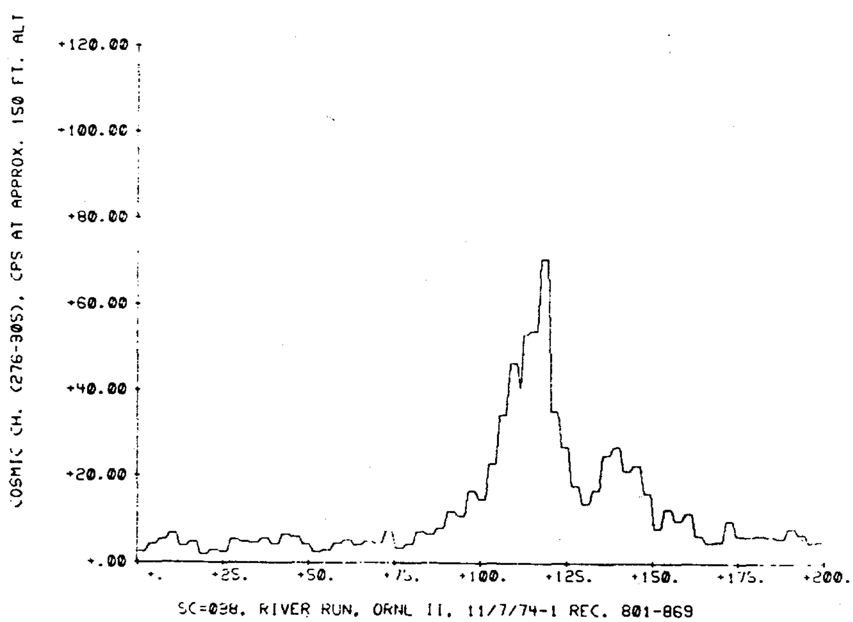


Figure G.4.2. Gamma count rate in cosmic window (2.76 to 3.06 MeV) versus time, 40-crystal array mounted on UH-1N helicopter.

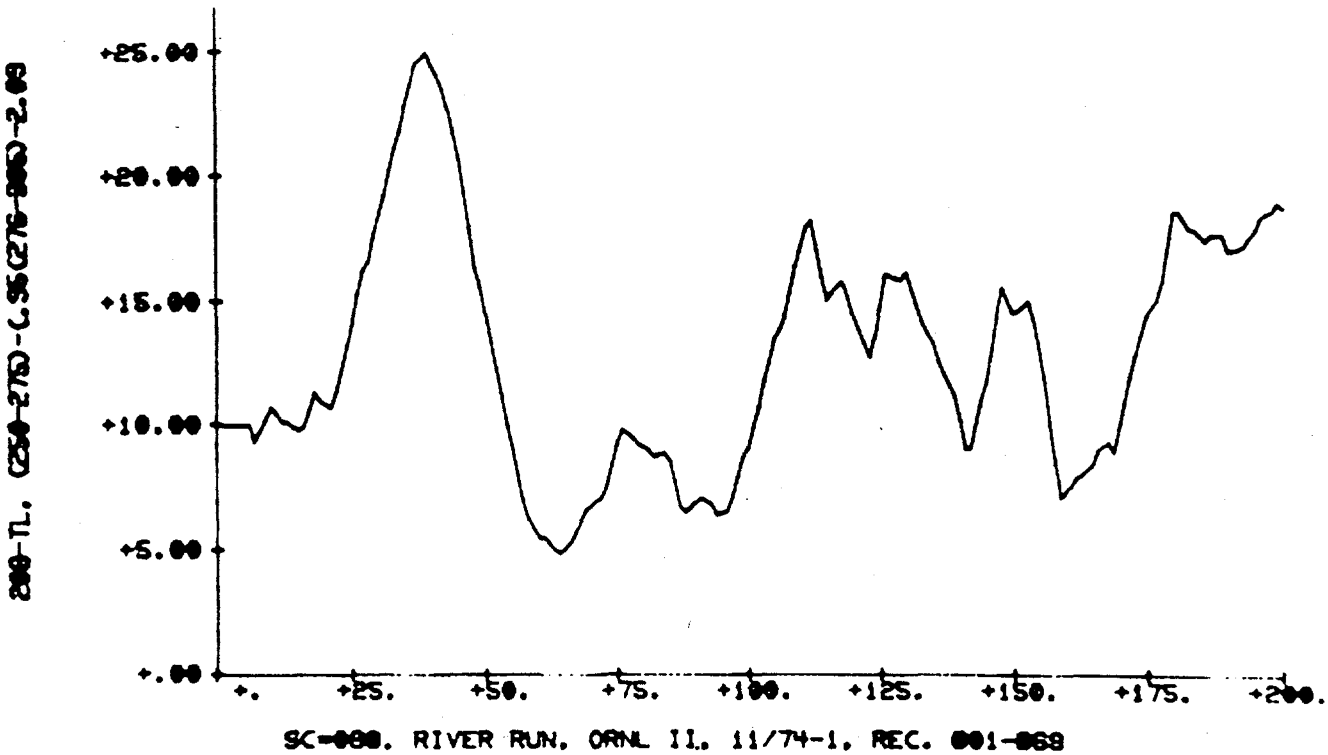


Figure G. 4. 3. Gamma count rate (cps) in ^{208}Tl window (2.50 to 2.75 MeV) from terrestrial radiation versus time, 40-crystal array mounted on UH-1N helicopter.

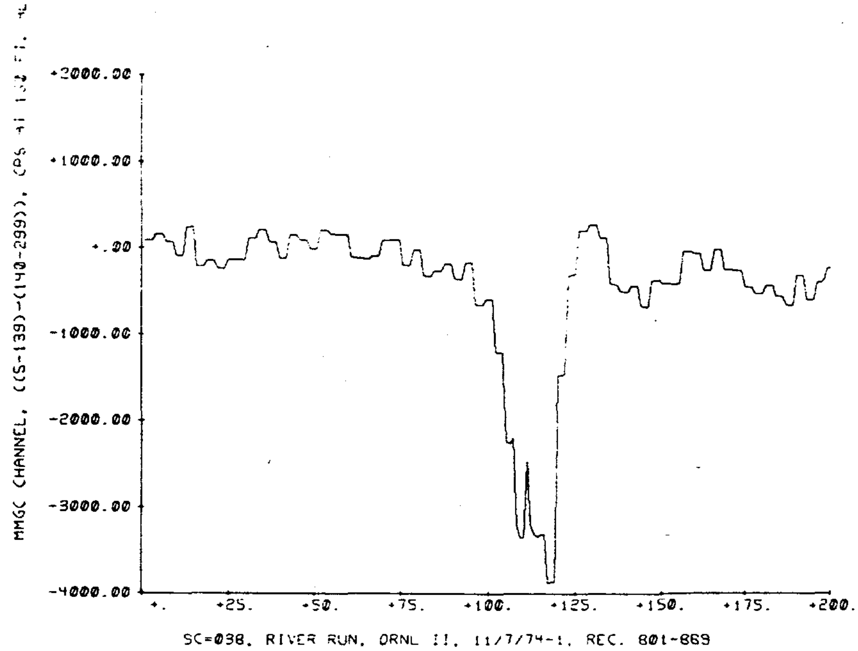


Figure G. 4. 4. Man-made gross gamma count rate versus time, 40-crystal array mounted on UH-1N helicopter.

The negative peak between 100 and 125 seconds indicates the anomaly.

A net spectrum was obtained of the peak. Records 33 thru 50 (99 thru 153 seconds) were summed. A background spectrum (records 51 thru 69) was then subtracted from the summed data. The resulting net spectrum is given in Fig. G. 4. 5. One can clearly identify the 0. 51 MeV pair production peak.

Initially, it was thought that a cosmic event caused the anomaly. A letter was sent to the World Data Center for Solar-Terrestrial Physics to see if it could be correlated with any cosmic event. Their search of all the data available failed to find any cosmic phenomena that could be associated with our event. A local cosmic shower could produce the intensity, but would not likely last that long.

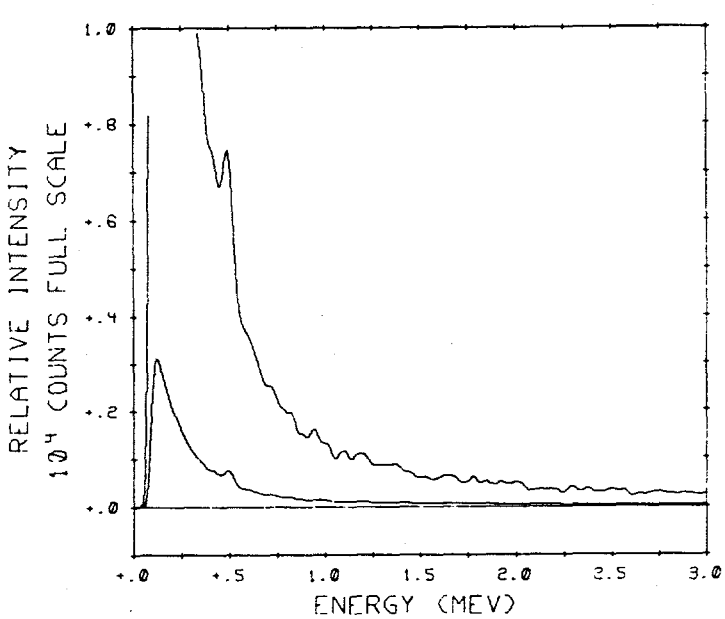


Figure G. 4. 5. Net high energy gamma ray pulse height spectrum in ARMS 40-crystal array.

A more likely cause of the anomaly may have been radiation from the Tower Shielding Facility (TSF). The reactor was running at a one-megawatt power level in a heavily shielded configuration. However, gamma rays from ^{16}N (activation product) in the water circulation systems could be observable from the air. The isotope, ^{16}N, has a 7.2 second half life and emits gamma rays of energy 6.1 MeV (69%) and 7.1 MeV (5%). The location of the anomaly, near Melton Hill Dam, was about 1.3 km from the TSF. A break in the hills at that location may have allowed near, or direct, line-of-sight to the cooling water systems. Small angle scatter (skyshine contribution) could have caused the high energy anomaly in the airborne detector system.

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